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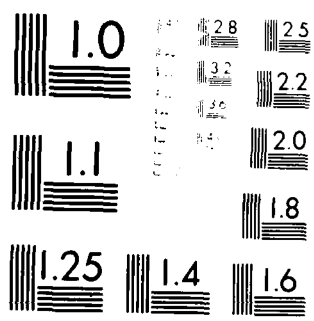

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Wright-Patterson Air Force Base, Ohio

AIRCRAFT AVAILABILITY: AN ACQUISITION DECISION STRATEGY

LaRita M. Decker, Captain, USAF
Stephen J. Guilfoos, GS-13

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Technological complexity in today's USAF weapon systems coupled with the limiting maintenance factors of skilled manpower, ageing aircraft and overburdened logistics support systems have caused aircraft to spend more time in maintenance. By increasing aircraft availability, through decreased maintenance time, additional sorties can be generated, thereby effectively increasing the number of available aircraft. Based on A-10 aircraft data, this thesis determined the statistical significance of relating reduced maintenance time to increased availability. Three measures of availability were investigated: (1) number of sorties generated; (2) number of aircraft waiting to fly; and (3) calculated aircraft availability. Secondly, this thesis quantified the relationship between increased availability and equivalent additional aircraft and investigated the possible use of this relationship as an acquisition decision strategy. Recommendations for further study and future application are presented. The thesis concludes with definitive examples of benefits to the Air Force, given a reduction in aircraft maintenance time.

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AIRCRAFT AVAILABILITY: AN ACQUISITION DECISION STRATEGY

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

LaRita M. Decker
Captain, USAF

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September 1982

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This thesis, written by

Captain LaRita M. Decker

and

Mr. Stephen J. Guilfoos

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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CHAPTER 1

INTRODUCTION

The United States military equipment strategy has evolved over the years to one of emphasizing advanced state of the art technology. This strategy of developing and deploying weapon systems with superior technology has allowed us to maintain a kind of parity with the more numerous, but less sophisticated, Soviet weapon systems (27:I-7). Lately, this parity has been eroded because of the Soviet's efforts towards upgrading their technology without a counter-balancing increase in the U.S. effort. U.S. production programs in the 1980s will begin to reverse this erosion in the USAF fighter force (Figure 1), but will not support the authorized 40 wings. The short-fall will become more acute if the unit cost of aircraft continues to rise (15:33). As an example of where our strategy of equipment superiority versus equipment quantity has led us, NATO currently has 2,800 combat aircraft while the Warsaw Pact countries have 4,700 (15:30). As Dr. Malcolm Currie, Director of Defense Research and Engineering, states (8:I-2):

> . . . without appropriate action on our part, the Soviets could achieve, on balance, a position of clearly perceived military superiority in terms of the combination of quantity and quality of their deployed military weapons at some point during the 1980's.

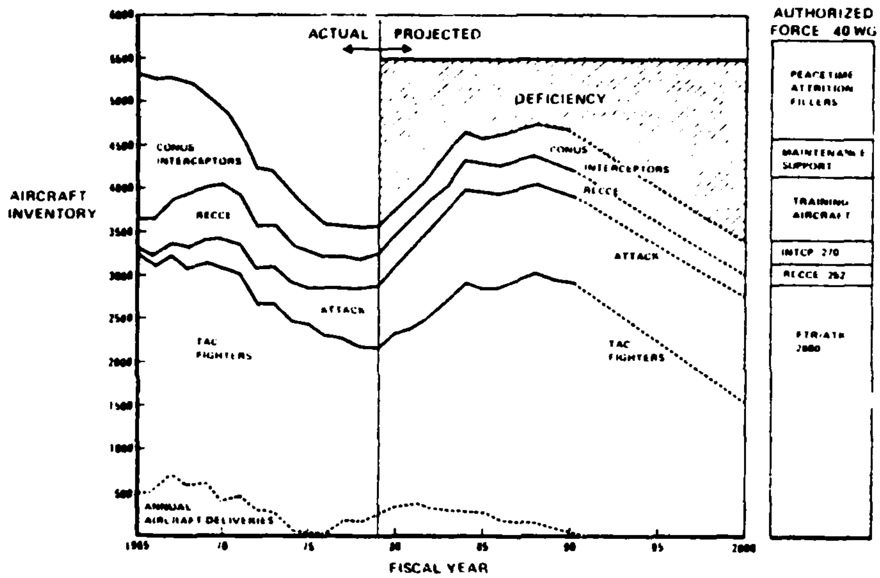


Figure 1. Aircraft Shortfall (15:133)

Figure 2 shows the shifting of the technology balance towards the Soviets. As this shift evolves, the overall parity balance may tip in favor of the Soviets. This could certainly impair the U.S. policy of deterrence. Deterrence obtains its power from the Soviet perception of our readiness to wage a war. Readiness implies the capability of maintaining a sufficient quantity of reliable and effective combat forces. For readiness to be a credible deterrent force, the Soviets must believe that the U.S. has the ability to deploy and engage our technologically superior combat forces.

Technological superiority, however, has come with increased technological complexity. This complexity, along

BASIC TECHNOLOGIES	U.S. SUPERIOR	U.S.-USSR EQUAL	USSR SUPERIOR
1. Aerodynamics/Fluid Dynamics		X	
2. Automated Control	X		
3. Chemical Explosives			X —
4. Computer	— X		
5. Directed Energy		X	
6. Electrooptical Sensor (including IR)	X —		
7. Guidance and Navigation	X —		
8. Hydro-acoustic	X —		
9. Microelectronic Materials and Integrated Circuit Manufacture	— X		
10. Non-Acoustic Submarine Detection		Cannot determine	
11. Nuclear Warhead		X	
12. Optics	X —		
13. Power Sources (Weapon)			X —
14. Production/Manufacturing	X		
15. Propulsion (Aerospace)	X —		
16. Radar Sensor		X	
17. Signal Processing	X		
18. Software	X		
19. Structural Materials		X	
20. Telecommunications	X		

The technologies selected have the potential for significantly changing the military balance in the next 10 to 20 years. The technologies are not static; they are improving or have the potential for significant improvements.

Figure 2. Relative U.S./USSR Standing in the 20 Most Important Basic Technology Areas (27:Table II-7)

with decreasing skilled manpower, has overburdened the existing logistic support systems. This equates to aircraft spending more time in maintenance; hence, aircraft availability is reduced and our readiness to wage war is decreased.

At least one authority, General Marsh (22:54), has raised the issue of the technological complexity of the sophisticated U.S. weapon systems versus the simplicity of the large numbers of Soviet systems. Most particularly, he did so in the context of our ability to keep sophisticated equipment flying and operating to minimum standards.

General Marsh recognizes this problem but believes that technological sophistication can also be used to increase system reliability and maintainability, the main building blocks of availability and readiness. ". . . Complex technology can also be used to make sophisticated systems smaller, cheaper, lighter, and more reliable [22:56]." These improvements can provide necessary force multipliers by achieving more sorties per given aircraft which allow our effective number of aircraft to increase without actually procuring more aircraft. In essence, increased aircraft availability can allow completion of the number of required sorties in lieu of using (and therefore buying) more aircraft. According to retired General T. A. Milton (24:55),

> Repairing damaged aircraft quickly is the modern version of aircraft replacement. That, along with the best possible inventory management, will have to serve as our answer to superior numbers.

However, the Air Force development and acquisition policies focus on aircraft operational performance and not on supportability which impacts maintenance time and, thus, availability. All too often, inflexible schedules and limited upfront funding preclude any complete effort to design more reliable, maintainable, and available weapon systems. Many times new technology is incorporated before the maintenance impact on the users is evaluated. For example, titanium, which is strong, lightweight and durable, is used to provide increased structural strength while reducing overall aircraft weight. However, in wartime, many forward operating locations will not have the expensive, sophisticated tools required to repair damaged titanium. Hence, an aircraft may have to wait to be repaired before returning to service, which reduces readiness. Air Force acquisition policy should focus, not only on aircraft performance, production schedules, and cost, but also on ways to increase availability.

DOD Directive 5000.1, dated 29 March 1982, addresses the requirement for a greater emphasis on availability early in the acquisition cycle. Specifically, it states:

> Readiness shall be established early in the acquisition process, and shall receive emphasis comparable to that applied to cost, schedule, and performance objectives. Logistic supportability shall be considered early in the formulation of the acquisition strategy and its implementation. Projected or actual achievement of readiness will be assessed at each milestone [36:7].

Following aggressive programs to promote increased aircraft

availability can allow the U.S. to provide a policy of deterrence through enhanced readiness of existing aircraft rather than total dependence on more new aircraft (26:10).

CHAPTER 2

PROBLEM STATEMENT

Problem Background

This thesis focuses on how to effectively increase the availability of U.S. systems. Availability and maintenance time are inversely related. In this chapter, availability and maintenance is discussed in terms of the mission cycle or aircraft turn time. Aircraft turn time is the time expended from one takeoff to the next takeoff. Equations for availability will be derived from aircraft turn time. This thesis concentrates on the maintenance aspects of turn time and the variables which directly affect maintenance time. In addition, a look at the aircraft acquisition cycle will demonstrate that availability is determined, albeit indirectly, early in the design stages. Finally, all of these areas are tied together in our research hypothesis and questions.

Aircraft Turn Time

Aircraft turn time, or a complete mission cycle, is defined as flying time plus maintenance turnaround time plus available time. Figure 3 breaks these times down into their components. The sequence of these components may vary in actual operations and are shown here for presentation

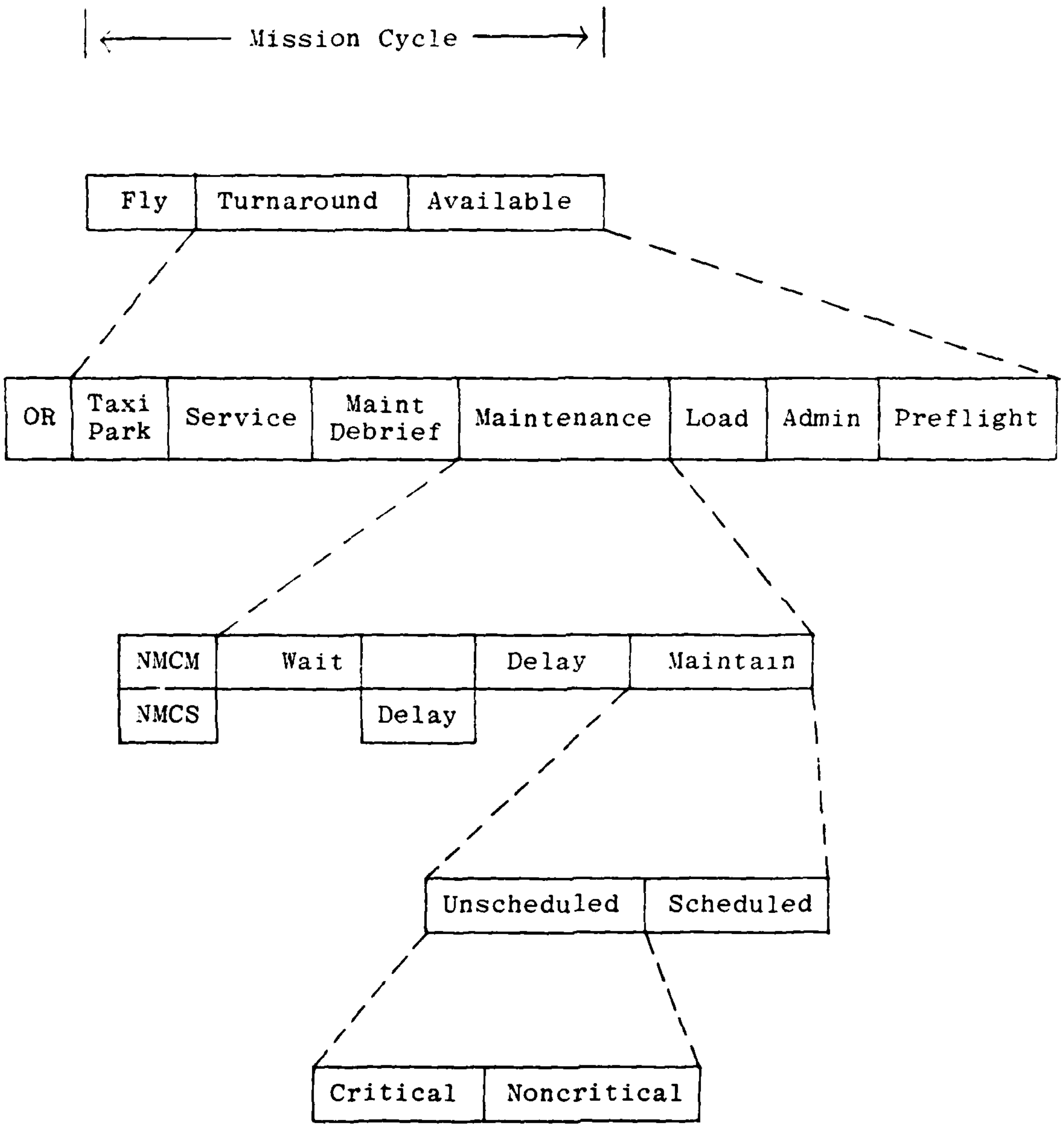


Figure 3. Elements of a Mission Cycle

purposes only. Every mission cycle will contain the Operationally Ready (OR) portion. Only when maintenance is required will the Not Mission Capable because of Maintenance (NMCM) portion be included. A similar situation applies for supplies in the Not Mission Capable because of Supply (NMCS) portion.

Figure 3 variables are defined by these elements:

1. OR - Operationally Ready
2. NMCM - Not mission capable because of maintenance
3. NMCS - Not mission capable because of supply
4. Taxi/Park - The time required to taxi and park the aircraft
5. Service - The time required to unload and post flight the aircraft
6. Maint Debrief - The time required for the aircrew to brief the status of the aircraft to Maintenance Shop
7. Wait - The time required to administratively schedule the aircraft for maintenance
8. Delay - The time spent waiting for resource (manpower or parts)
9. Maintain - The time spent in maintenance
10. Scheduled - The time spent on regularly scheduled preventative maintenance for reliability and safety
11. Unscheduled - The time spent to repair an in-service failure or malfunction
12. Critical/Non-Critical - Refers to the essentiality of the failed item for full mission capability
13. Load - The time spent preparing the aircraft for the next flight

14. Admin - Administrative time spent waiting for paperwork

15. Available - Time spent in ready status waiting for next scheduled flight

16. Preflt - The last minute items required before aircraft is released for takeoff

The maintenance part of NMCM is further broken down into unscheduled and scheduled maintenance. Unscheduled maintenance contains both critical and noncritical actions required for the aircraft to be returned to full mission capability. The purpose for the detailed breakdown of the maintenance portion is to be able to eventually describe aircraft availability in terms of maintenance time. Maintenance time will be considered the controllable variable, while the others will be considered uncontrollable. That is, their variability between flights is very small when compared to maintenance time variability.

Scheduled maintenance is generally a form of preventive maintenance. The Air Force accomplishes the time phase inspections and maintenance to regularly check various aircraft systems. What is done at each phase inspection is a function of the particular aircraft. The service life, and wearout characteristics for various components such as oil, hydraulic fluid, and structural items. Scheduled maintenance is designed to provide regular care, inspect subsystems, and replace items before they wear out. These actions are performed to prevent component and system failure rates from increasing over the design levels (2:165-166).

On the other hand, unscheduled maintenance is a function of chance failure during the operation of a system. Its purpose is to restore system operation as soon as possible by repairing, replacing, or adjusting items which have malfunctioned (2:165). Noncritical items are often deferred either until the next scheduled maintenance or until there is an adequate wait or delay time in the mission cycle to allow the work to be completed.

Production Oriented Maintenance Organization (POMO) and now Combat Oriented Maintenance Organization (COMO) are maintenance philosophies which have been instituted to reduce the maintenance turn times in operational units. Even so, maintenance time continues to be the most variable component of aircraft availability. The effects of POMO and COMO do not influence the results of this thesis and are not further addressed.

All maintenance actions are recorded on the AF Forms 781 or aircraft maintenance forms. Whenever there is a maintenance deferral and the aircraft is allowed to fly, the required maintenance action is annotated with either a "Red-Dash" or "Red-Diagonal", or "Red-X" on the form. The dash and diagonal are a shorthand form of displaying the length of deferral time. A "Red-X" implies that the required maintenance is critical and the aircraft cannot be released for flying until the maintenance is completed.

Availability can be increased most directly if the critical maintenance time associated with "Red-Xs" is reduced.

Maintenance can be portrayed in numerical figures by a concept called "maintainability." Maintainability is the probability that an item is repaired within a designated amount of time (2:195). An aircraft's maintainability is increased by decreasing the time required for maintenance. This includes not only the time to repair but also the time it takes to get at the failed component. For example, the amount of maintenance time required is a function of the number of fasteners to be removed on a panel and the accessibility of the failed component behind that panel. Maintainability is not specifically addressed later in this thesis. However, a basic knowledge of maintainability is helpful in understanding availability.

Maintenance actions may occur consecutively or simultaneously. Which alternative depends on the failed component or components and the number of repair men working. In quantifying maintenance time with respect to aircraft turn time, we will use maintenance clock time. Maintenance clock time refers to the total clock downtime a system spends in repair and is not necessarily the sum of all the individual repair times for all the components repaired. Hence,

$$T_M = T_S + T_U + T_D \qquad (1)$$

where

T_M = Total maintenance clock time

T_S = Clock time - scheduled maintenance

T_U = Clock time - unscheduled maintenance

T_D = Delay clock time

Delay clock time is defined as all other maintenance downtime not spent in actual repair. It can represent waiting for parts or manpower to perform the repair. In reference to the Elements of a Mission Cycle (Figure 3, page 8):

$$T_{POST} = T_T + T_S + T_B \qquad (2)$$

where:

T_{POST} = Post flight time

T_T = Taxi and park time

T_S = Service time

T_B = Maintenance debrief time

and

$$T_{PRE} = T_L + T_A + T_P \qquad (3)$$

where:

T_{PRE} = Preflight time

T_L = Loading time

T_A = Administrative time

T_P = Preflight time

Combining Eqs (1), (2), and (3) with T_F (flying time) and T_W (ready status, waiting to fly), mission cycle time (T_{MC}) is defined as:

$$T_{MC} = T_F + T_W + T_{POST} + T_{PRE} \tag{4}$$

Availability

After mission cycle has been defined in terms of all of its elements, one needs to translate mission cycle time into aircraft availability. Availability of an aircraft is defined as the probability that, given the aircraft's subsystem failure rates and repair times, the aircraft will be available to fly in the future. It is the ratio of flying and waiting time to total mission cycle time.

That is

$$A = \frac{T_F + T_W}{T_F + T_W + T_M + T_{POST} + T_{PRE}} \tag{5}$$

where:

- A = Availability
- T_F = Flying time
- T_W = Waiting time (Alert Status)
- T_M = Maintenance time
- T_{POST} = Post flight time
- T_{PRE} = Preflight time

or

$$A = \frac{T_F + T_W}{T_{MC}} \qquad (6)$$

where:

T_{MC} = Mission Cycle time

Thus, we can increase availability by decreasing any of the variables in the denominator of Eq (5) except flying or waiting time.

<u>Maintenance Factors</u>

The variables T_{POST} and T_{PRE} cannot be appreciably decreased under normal aircraft operations. Therefore, our focus will be on reducing maintenance turn time (T_M) and the resulting increase in aircraft availability.

To understand maintenance turn time, the underlying factors which affect maintenance need to be discussed. Some of these variables are complexity and age of aircraft, manpower, and logistics support.

As seen in Figure 4, maintenance man-hours per sortie are directly related to aircraft complexity. This means that more maintenance is required to keep an aircraft available for flying. Percent mission capable is a relative measure of aircraft availability. Figure 4 also shows that as complexity and maintenance man-hours increase, the aircraft availability (% Mission capable) decreases (15:32).

Aircraft	Procurement costs, $M	Relative complexity	% Mission capable	Mean flight hr. between failure	Maintenance man-hr. per sortie
A-10	5.5	Low	67.4	1.2	18.4
A-7D	6.0	Medium	61.4	0.9	23.2
F-4E	6.5	Medium	65.9	0.4	38.0
F-15	15.0	High	55.7	0.5	33.6
F-111F	23.0	High	63.1	0.3	74.7
F-111D	23.0	High	34.4	0.2	98.4

Figure 4. Complexity Increases Maintenance (15:32)

The U.S. has many aging aircraft systems which require significant maintenance hours. Figure 5 shows the numerical age distribution of the F-4 aircraft as of May 1981. The F-4 aircraft has been our primary all-purpose fighter since the early 1960s. The B-52 has been rebuilt through extensive modifications and is expected to be our primary long range bomber through the 1980s. General Bryce Poe, II, has noted that the average age of USAF aircraft rose from eight and one-half years old to more than 11 years old over the past ten years. and that just under 66 percent of the Air Force inventory is nine years or older (28:36).

The older an aircraft becomes, the greater the amount of maintenance usually required to keep the aircraft operational. According to Bazovsky, as an aircraft approaches the end of its useful life and enters its wearout phase, the failure rate increases exponentially (2).

	Age, yr.						
Service unit	0-3	3-6	6-9	9-12	12-15	15-18	Total a/c
USAF		109	81	436	562	76	1264
ANG					211	213	424
USAFR					18	13	31
Total		109	81	436	791	302	1719
% of total a/c	0	6	5	25	46	18	

Figure 5. F-4 Age Distribution (15:32)

Maintenance problems are exacerbated by declining capability in America's available manpower. Figure 6 depicts military manpower as a percent change in the 17 to 19 year old population (25:8).

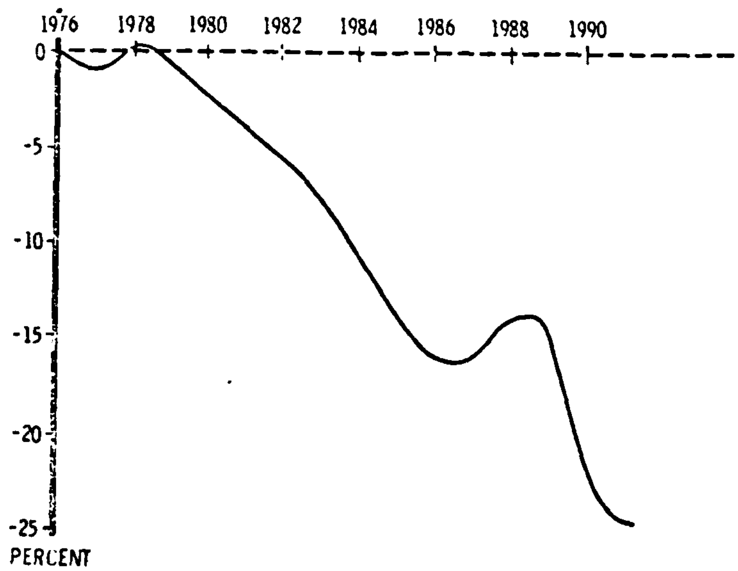


Figure 6. Military Manpower Pool Percentage Change In 17 to 19 Year Old U.S. Male Population, 1976-1990

The number of eligible people for military service is expected to decline through the 1990s. This undesirable trend, when added to the weapon system complexities, and the anticipated decline in scholastic aptitude may result in a more costly, less capable, and less responsive work force. Paradoxically, while the teenage population declines, the over-30 work force will increase. The skilled DOD employees in this age group will become targets of recruitment by

civilian industry. Further increasingly complex weapon systems will require even greater numbers of skilled manpower (4; 25:7,8).

Given increased aircraft complexity and age, and the decreasing number of available people to train, the logistics support systems will become severely taxed. Logistics support systems refer to spare parts inventory, test equipment, and transportation. If the trend continues, the remove and replace philosophy will eventually expand to cover all components and the repair function will move more and more to centralized locations. This will necessitate a higher spares inventory at the user's level. More sophisticated built-in tests for on-board aircraft will be required. This trend can push the maintenance function to a higher level of complexity which will require even more specialized skills and support systems (4). These sophistications also create mobility constraints. With limited maintenance manpower and skills, the centralized repair centers, and the length of the spares pipeline, rapid mobility of forward operating locations can be severely hampered (4).

The relationship of these factors with aircraft maintenance time is shown in Figure 7, which is a causal loop diagram that shows that each of the factors directly affecting maintenance time causes maintenance time to increase. The diagram can be read as follows: as a factor increases (+) or decreases(-), maintenance time increases.

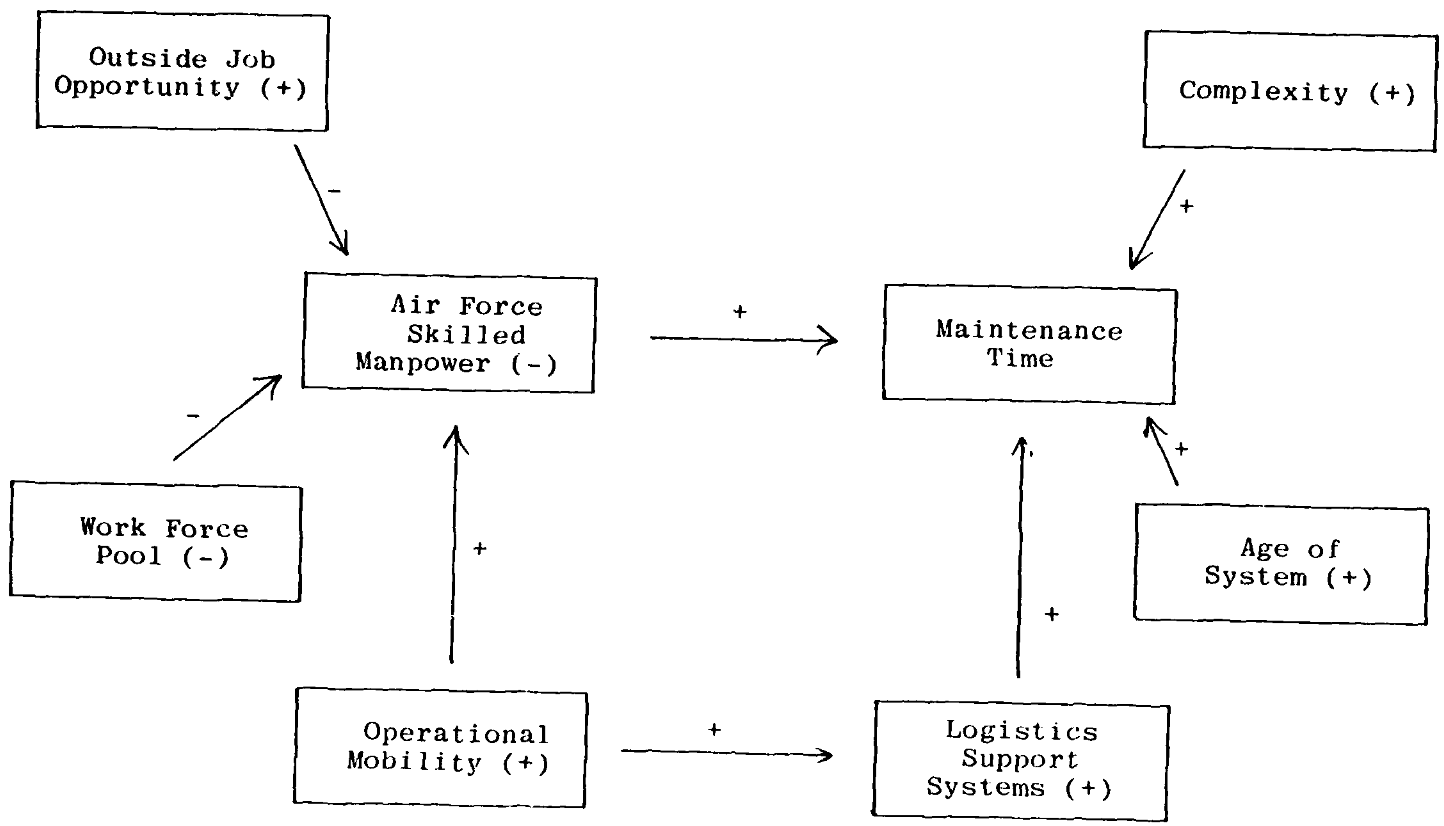


Figure 7. Weapon System Maintenance Time Causal Loop Diagram

Operational Environment

Maintenance has been defined in terms of aircraft mission cycle and its impact on availability addressed. In addition, the major factors which influence maintenance have been examined. The new focus is now on the applications of maintenance in operational use. There are two major operational environments: peacetime and wartime. Peacetime use is characterized by normal day to day operations, by-the-book maintenance, and occasional surge exercises to test wartime readiness. Wartime, on the other hand, is characterized by intense operations with nonstandard maintenance.

In peacetime, availability has often been equated with operational ready (OR) rates or mission capability (MC) rates. This relationship is misleading when carried over to wartime readiness or availability. The mission cycle rate is directly dependent on the number of takeoffs and the mission cycle time is directly tied to the flying schedule required for aircrew training. The high cost of fuel and the availability of simulators keep flying to a minimum, thus creating a rather long mission cycle. Also, if an aircraft is not scheduled for another flight for many days. maintenance actions may be postponed rather than fixing the aircraft right away. Often, the peacetime stocking of spares policy causes time delays in waiting for parts. As General Marsh observed (22:55),

> . . . we could generate OR rates, if we wished, by increasing our peacetime spares or using war-readiness

stocks. Peacetime rates are not indicative of wartime performance, but rather reflect operations which need provide only enough sorties to insure aircrew proficiency under economic constraints.

Budgetary changes have been instituted which would increase these spares stocks, even at the expense of additional aircraft (22:55). The mission capability rates are goals developed primarily for programming and budgetary purposes and not as an evaluation for operations. The Air Staff does not expect these goals to be achieved under "real world" peacetime conditions because of various constraints (6:1). Hence, extreme care should be taken when discussing peacetime availability and methods of increasing this availability.

Various sortie surge exercises have been conducted recently which demonstrate the capability of increasing sortie rates (22:55). These surge exercises occur over short time periods and do not relate to the normal steady state maintenance conditions. They are special fully supportable maintenance conditions. For example, an exercise called Coronet Eagle simulated wartime conditions and the F-15 sustained over six times its peacetime rate. The A-10 and F-111 have also demonstrated similar increases over peacetime sortie rates (22:55). These surge exercises point out that it is not the OR or MC rates, but the mission cycle or turnaround time which determines aircraft sortie generation capability (availability).

There are constraints to increasing aircraft availability in peacetime, but in the limit, peacetime surge exercises approximate wartime usage. There are some facets of wartime maintenance that are not allowed during peacetime surges and will have a dramatic impact on aircraft availability. The three major facets are:

1. War Readiness Spares Kit (WRSK). The WRSKs are prepositioned kits with additional spares which are to be used only under wartime conditions. The purpose of the kit is to have enough spares on hand for the first X days of a war and not to depend upon the normal logistics supply pipeline.

2. Aircraft Battle Damage Repair (ABDR). ABDRs are maintenance actions taken in wartime to maximize the availability of aircraft through effective use of maintenance resources to assess, repair, defer repair, or cannibalize battle damaged aircraft (38:5).

3. Partial Mission Capability (PMC). Aircraft will be allowed to fly with only partial mission capability (11:12; 38). For example, if an aircraft cannot perform air-to-ground missions, but can be outfitted with a camera pod, the aircraft may be allowed to do Reconnaissance missions.

Johnson, in an analysis study of A-10 availability, modeled the A-10 in a wartime scenario with and without battle damage repair (17). He found that special temporary

repair procedures would have provided an additional 177 sorties. If 50 percent of the damaged aircraft could be repaired in less than six hours, then an additional 114 sorties could be generated (11:1; 14; 17:13). Without the capability of rapidly returning an aircraft to operational use, the theater commander could expect to lose a significant number of sorties while waiting for repair actions (11:iii; 38:3,4). In some cases, rapid repair could conceivably mean the difference between victory and defeat (11:18).

Since the major factor in increasing wartime aircraft availability is maintenance, we need to take a detailed look at wartime maintenance and ABDR. As stated in the ABDR Program Management Directive (38:3), ". . . the overall objective of rapid ABDR is to maximize wartime aircraft availability and sortie rates at the lowest possible cost with a finite number of aircraft." ABDR effects the best possible repair within the constraints of time, material, and manpower in order to return the aircraft to some level of operationa condition. In peacetime, maintenance standards and repair criteria are geared to maintaining a long operational life (11:3; 38:3). In the event of war, the carrying out of repairs to these standards would take a long time and eventually would lead to a lack of available aircraft. It is therefore essential for the USAF to develop techniques which would effect speedy repairs and return battle damaged

aircraft to operational use in minimum time (11:3). The acceptable limits for damage and its repair are less restrictive than those used in peacetime. Further, these repair procedures are not to be used for any purpose other than battle damage repair under combat conditions (34:1-1). This is because repairs are not intended to be full restoration of service life, but rather, "one more flight" in nature.

To sum up the impact of decreased maintenance turn time in aircraft availability during wartime, retired General T. A. Milton says (24:55):

> The Aircraft Battle Damage Repair Program . . . is a new and imaginative effort to make what we have look like more than we have by cutting down the time it takes to get a wounded airplane back in action.

Acquisition Strategy

The effect of various components of maintenance on aircraft availability and their impact during intense operational use have been identified. Unfortunately, today's aircraft availability is a direct descendant of what the Air Force conceptualized and contracted to buy in the past. Air Force acquisition strategy, complete with its management policies, budgetary constraints, goals, and cycle time, is the primary force in shaping the limits of aircraft availability in the future. In order to improve aircraft availability through decreased maintenance turn time, adequate effort must occur in the aircraft conceptualization and design stages of the acquisition cycle.

By early consideration of maintainability in aircraft design, the number of maintenance actions and their cycle times can be greatly reduced. For example, aircraft configuration with maintainability in mind may have avoided the F-4 radio accessibility problem of putting a radio beneath the pilot's ejection seat forcing removal of the seat to repair the radio which failed frequently. Another example is the use of special wing skin fasteners on the F-15 which, because they are unavailable in the marketplace, cannot be removed to change deteriorating foam in the fuel cells.

By using subsystems designed with the frontier of technology information, the Air Force is taking unnecessary risks in complexity and maintenance. Exotic materials and designs may require special tooling and skills not readily available. Untried designs often lead to unforeseen maintenance problems. For example, composite materials in large size major aircraft structures require an autoclave (heat and pressure applied over time) to cure a repair patch. Not very many operating bases will have access to these large autoclaves. Without designing in maintenance solutions to these problems, the aircraft's availability in wartime is severely degradated.

All too often, serious maintainability considerations in design are dropped because of budgetary constraints and the desire to include the newest technology. Today's

acquisition strategy is to provide the most technologically advanced weapon system to counterbalance the growing Soviet threat.

Research Objective

The research objective of this thesis is to evaluate the feasibility of using an incremental reduction in maintenance time as a significant multiplier of aircraft availability by generating more sorties per given aircraft. We intend to study the sensitivity of aircraft availability to reductions in maintenance turn time and evaluate aircraft availability as a possible acquisition strategy.

Research Questions

Investigation will center on the maintenance portion of the mission cycle. Aircraft availability is most crucial in wartime and we will quantify the impact of maintenance time reductions on aircraft availability in wartime. If there is a significant improvement in aircrait availability, the thesis will investigate ways of quantifying this availability as a decision strategy in Air Force acquisition.

To that end, the research questions are:

1. How sensitive is aircraft availability to reduced maintenance times?

2. Can increased availability through reduced maintenance time be related to equivalent additional aircraft? If so, should this relationship be addressed as an acquisition decision strategy?

CHAPTER 3

RESEARCH METHODOLOGY

Scope and Limitations

The purpose of Chapter 3 is to describe the research methodology used in answering the research questions proposed in Chapter 2.

In focusing this thesis on reducing the maintenance clock time required to repair aircraft, an evaluation is made as to the significance of its relationship with aircraft availability. If a significant relationship exists, the focus shifts to using a measure of aircraft availability as an acquisition decision strategy.

Before continuing, a few words are necessary to explain the terms significance and relationship. Significance is used in reference to statistics. That is, specific statistical tests will be run on the data to determine its statistical significance. The term relationship refers to the mathematical association between maintenance time reduction and aircraft availability. Hence, "the significance of the relationship" refers to the statistical significance of the mathematical relationship between maintenance time reduction and aircraft availability.

Study Framework

The study framework encompasses the area of aircraft availability and how availability is affected by maintenance clock time. A computer simulation model was developed to examine the relationship between mission cycle, or turn time (which is a function of maintenance time), and availability. Maintenance data from the Viet Nam conflict (3; 7; 9; 10; 13; 14; 16; 18; 19; 20; 33; 35) stored at the Combat Data Information Center (CDIC) at Wright-Patterson AFB, Johnson's A-10 study (17), and peacetime maintenance data (1) were reviewed.

Historical data has not been collected in a manner which facilitates use in this thesis. Both peacetime and wartime data bases required extensive adjustments to the data to extract maintenance clock time. It was found that the maintenance clock time for peacetime did not adequately reflect aircraft availability. During peacetime, flying schedules are not intensive and often maintenance may not occur immediately after a sortie. Therefore, recorded maintenance time is confounded by other variables and is not adequate for this thesis.

In addition, the Viet Nam data collected for wartime could not be used. Viet Nam was an extended conflict and the data compiled from the AFLC Depot Rapid Area Maintenance (RAM) teams was measured in terms of man days to repair severely damaged aircraft. Our thesis assumes a 30 day

conflict in which aircraft availability is a critical issue with repairs required in a matter of hours.

Johnson's study evaluated the number of sorties generated based on standard repairs versus temporary repair procedures (17). Temporary repair procedures are performed in the field and are aimed at obtaining one more sortie rather than standard repairs to obtain a totally operational aircraft. Johnson's study is in line with the Air Force Battle Damage Repair Program and measures repair in terms of hours. Therefore, Johnson's A-10 study provided the base-line data for this thesis..

The maintenance data from the A-10 study is a probability distribution of repair times required to repair a hit from a 23mm HEI (high explosive incendiary) projectile. While the A-10 may not be extendible to all other aircraft, if A-10 aircraft availability is significantly sensitive to reduced maintenance time, future study on other aircraft is warranted.

Figure 8 shows the A-10 probability distributions of repair times for "standard repair procedure" and "temporary repair procedures." Standard refers to the normal by-the-book procedures, while temporary refers to the forerunner of what is now known as battle damage repair. As seen in Figure 8, by using the temporary repair procedures, it is possible to reach a higher probability of repair sooner. How these repairs are made is not the thrust of this thesis,

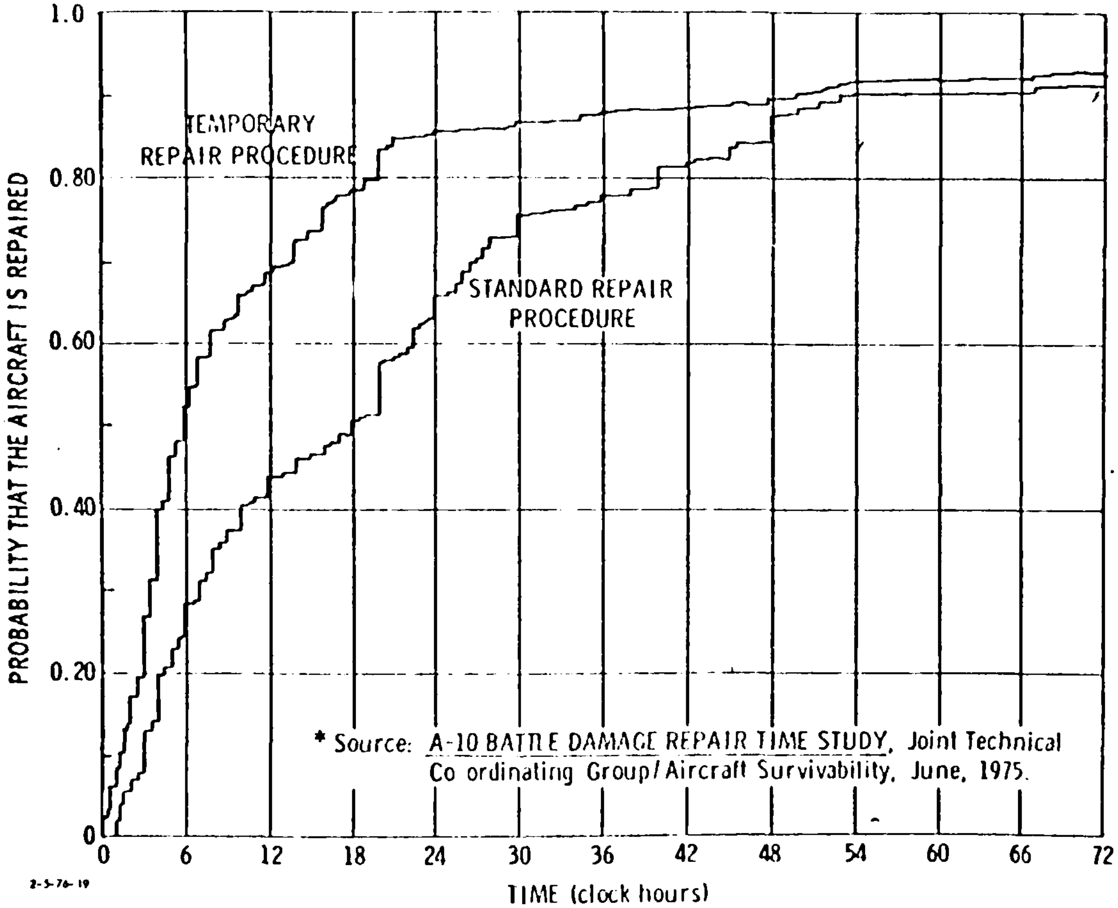


Figure 8. Probability Distribution of Repair Times (17:14)

but rather, the thrust focuses on whether reduced maintenance time significantly increases aircraft availability.

The simulation model developed for this thesis uses the standard repair probability distribution as the baseline repair times. Successive runs of the model were made reducing the repair time by 10 percent. The temporary repair procedure distribution represents approximately a 40 percent reduction from the standard distribution. By evaluating the results of these successive simulation runs, it was possible to quantify the effects of reduced maintenance time on aircraft availability.

Model Description

A Q-GERT computer simulation model was used to assess the effect of incremental reduction in maintenance time on availability. The Q-GERT simulation language provides a method for modeling systems and permits direct computer analysis (29:viii).

This model network is based on the following assumptions:

1. Baseline of 48 aircraft to start
2. A sortie length of one hour
3. Maintenance time follows the standard repair distribution for the A-10
4. Turntime for aircraft of one hour
5. Sortie generated every .5 hours
6. A 24 hour flying day

7. A 24 hour maintenance day

8. Sufficient maintenance personnel available

9. Sufficient spares, test equipment, etc., available

10. Sufficient flight crews available

11. An attrition rate of 3 percent

12. Length of simulation is 30 days

An aircraft squadron of 48 aircraft and a sortie length of one hour are not uncommon. In addition, a 24 hour flying day and a 24 hour maintenance day are not out of line in wartime. The assumptions of sufficient personnel and other logistics support provide a means of making aircraft availability dependent on maintenance clock time. These assumptions, which guide this thesis, also provide a best-case or optimized situation. Therefore, actual results in the field are likely to be even more significant than those shown in this thesis. An attrition rate of 30 percent was used previously in the Johnson study and a 30 day conflict is currently a common scenario.

A diagram of the Q-GERT network, a listing of the computer program, and examples of computer output can be found in Appendix A. The A-10 study used a damage rate of 13 percent and an attrition of 3 percent. The Q-GERT model uses both the 13 percent damage rate and 3 percent attrition rate as a beginning point. The attrition rate was then kept constant for all subsequent computer runs. A sensitivity

study on battle damage was conducted by changing the damage rate to an 8 percent damage rate and an 18 percent damage rate and selected rates in between based on initial findings. Appendix A also has a matrix listing of all pertinent runs of the model. The A-10 study used the approach of comparing the two repair time distributions on the number of sorties generated.

Research Question #1 Methodology

Research Question #1. How sensitive is aircraft availability to reduced maintenance times?

A set of simulation runs is used to answer the first research question. The dependent variable of aircraft availability is measured by the number of sorties generated. The independent variable is the standard maintenance repair time as the baseline and 10 percent incremental reductions up to a 50 percent reduction. All the other variables in the model are kept constant. The model is set up to generate one sortie every half hour for 30 days, given there is an aircraft available to fly. Statistics for the 30 days started after the first 24 hours to eliminate model start-up variations. In the model, there are only two reasons why an aircraft would not be available to fly: one, the aircraft has been lost, or two, the aircraft is in maintenance.

The output of the model (examples can be found in Appendix A) consists of the number of sorties generated (number of observations for node 7, turn time). As the

input variable of repair time is varied. the output of sorties generated is evaluated relative to the baseline (zero percent reduction in maintenance time). A T-test on groups (23) is incremental maintenance time reduction relative to the baseline distribution. A sample size of ten was used for each simulation run listed in Appendix A. A sample size of ten was selected as a number less than 30 in line with the Student-t distribution. Ten is a breakpoint usually used by statisticians. At sample sizes greater than 30, the Student-t distribution approximates the normal distribution.

The t-Test for group data tests the distribution's mean values for all ten simulation runs. The null hypothesis (H_0) is that the two means are the same. The alternate hypothesis (H_A) is that the two means are different.

<u>Two Tail Test</u>	<u>One Tail Test</u>
H_0: $\text{Mean}_1 = \text{Mean}_2$	H_0: $\text{Mean}_1 > \text{Mean}_2$
H_A: $\text{Mean}_1 \neq \text{Mean}_2$	H_A: $\text{Mean}_1 \not> \text{Mean}_2$

For a two tail test, the rejection region for the null hypothesis, from the SPSS (Statistical Package for Social Sciences) t-Test groups, is when the "2-Tail Prob" value is less than alpha, the null hypothesis is rejected in favor of the alternate hypothesis.

For a one tail test, divide the "2-Tail Prob" value by two and compare it to alpha.

If the null hypothesis is rejected, then there is a significant difference between the groups of data at a given alpha level. In this thesis, it means that there is a significant difference between the baseline condition distribution and the incremental time reduction condition distribution. Hence, if the deviation is in the proper direction, there is a positive answer to research question 1.

Listings of the SPSS computer programs can be found in Appendix B along with example output.

Research Question #2 Methodology

Research Question #2. Can increased availability through reduced maintenance time be related to equivalent additional aircraft? If so, should this relationship be addressed as an acquisition decision strategy?

The second set of simulation runs is used to answer the second research question. The dependent variable is again the number of sorties generated. The independent variable is the number of aircraft in the start of the simulation and an incremental increase up to five additional aircraft. These simulation runs kept the maintenance time constant at the baseline condition. By equating the availability results with the previous simulation runs for reduced maintenance time with the number of sorties generated as the common variable, then it is possible to quantify the

relationship between reduced maintenance time and equivalent additional aircraft. Through the transitive property (If A = B and B = C, then A = C), it is possible to equate aircraft availability (B) in each equation and derive a numerical relationship between percent maintenance time reduction (A) and equivalent additional aircraft (C). This numerical relationship makes it possible to quantify an acquisition decision strategy.

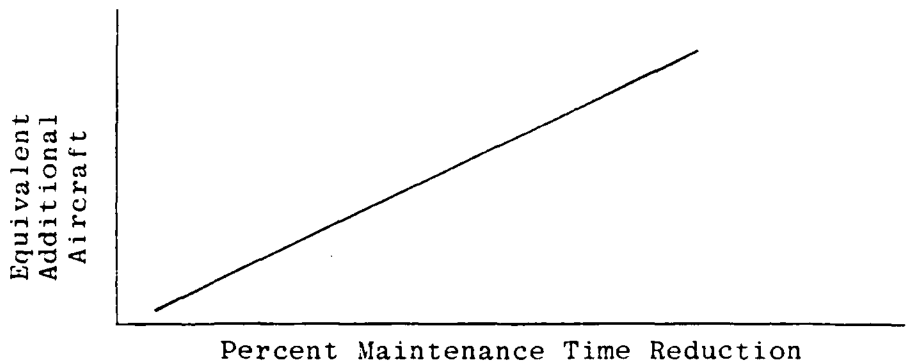


Figure 9. Equivalent Additional Aircraft Versus Percent Maintenance Time Reduction

To test for significance of the additional aircraft to the baseline condition, a t-Test for groups is again run. The statistical techniques and rejection region are identical as described for research question 1 and are not repeated here. There were also ten simulations of each condition.

Once a significant difference was found for both the reduced maintenance time and additional aircraft, a regression analysis was run for both. The dependent and

independent variables remained as they were for the simulation runs. The regression analysis defined each relationship of sorties generated with percent maintenance reduction and with additional aircraft respectively. A global F test was performed on each equation to determine if the coefficients were significantly nonzero. Coefficients which are significantly nonzero can be used to specify a given relationship such as reduced maintenance time to aircraft availability. The null hypothesis is that all the coefficients are zero and the alternative hypothesis is that they are significantly nonzero.

$$H_0: \text{Coeff}_i = 0; \text{ all } i$$
$$H_A: \text{Coeff}_i \neq 0; \text{ at least one } i$$

The rejection region is when the SPSS calculated F value is greater than the table F value at a chosen alpha level with the appropriate degrees of freedom. If the null hypothesis is rejected in favor of the alternative hypothesis, then these two equations are significantly nonzero with the same dependent variable of aircraft availability. Through the use of the mathematical law of transitivity, as previously discussed, these two equations can be equated to each other. Hence, with aircraft availability as the common variable, equivalent additional aircraft can be quantified in terms of reduced maintenance time. This forms the basis for an acquisition decision strategy.

CHAPTER 4

FINDINGS

Procedure

Intuitively, there is a positive relationship between reduced repair time and increased aircraft availability, and additional aircraft and aircraft availability. However, the significance of these relationships is not obvious. Our procedures involve a very highly structured process to determine statistically significant relationships. In addition, a sensitivity analysis of derived equations was performed.

The Q-GERT simulation model calculates its statistics as average values over the length of the simulation run (time). It also averages each simulation run together for its summary statistics. Each run was used to generate data distributions for the t-Test on groups, while the summary statistics provided the data for the regression analysis.

Graphs were developed to help interpret the numerical data. Graphs from the regression analysis equations were generated early in the analysis to help verify a priori expectations.

Sorties Generated Approach

The number of sorties generated come from the number of transactions through node 7, in the Q-GERT model, the turn time statistics node. It represents the number of complete sorties over the length of the simulation run.

Finding #1. Since the simulation model generates a sortie every half hour as long as there is an aircraft waiting to fly, a 30 day simulation run can generate a maximum of 1440 sorties. This situation was experienced on many individual simulation runs.

Finding #2. The constant attrition rate of 3 percent of the sorties generated caused an average of 43.2 aircraft to be lost during a simulation run of 30 days. This implies that, in the later stages of a simulation run, there are very few aircraft remaining in the mission cycle.

Finding #3. Figure 10, Sorties Generated Versus Percent Repair Time Reduction, and Figure 11, Sorties Generated Versus Additional Aircraft, depict the positive relationship between the dependent and independent variables. (The terms repair and maintenance are used interchangeably.) Damage rates of 8 percent, 13 percent, and 18 percent were run and the data fell where expected. The lower the damage rate, the greater number of sorties generated. It was also believed that damage rates between these three rates would generate curves which would fall between these curves accordingly. Totally unexpectedly, the 15 percent damage

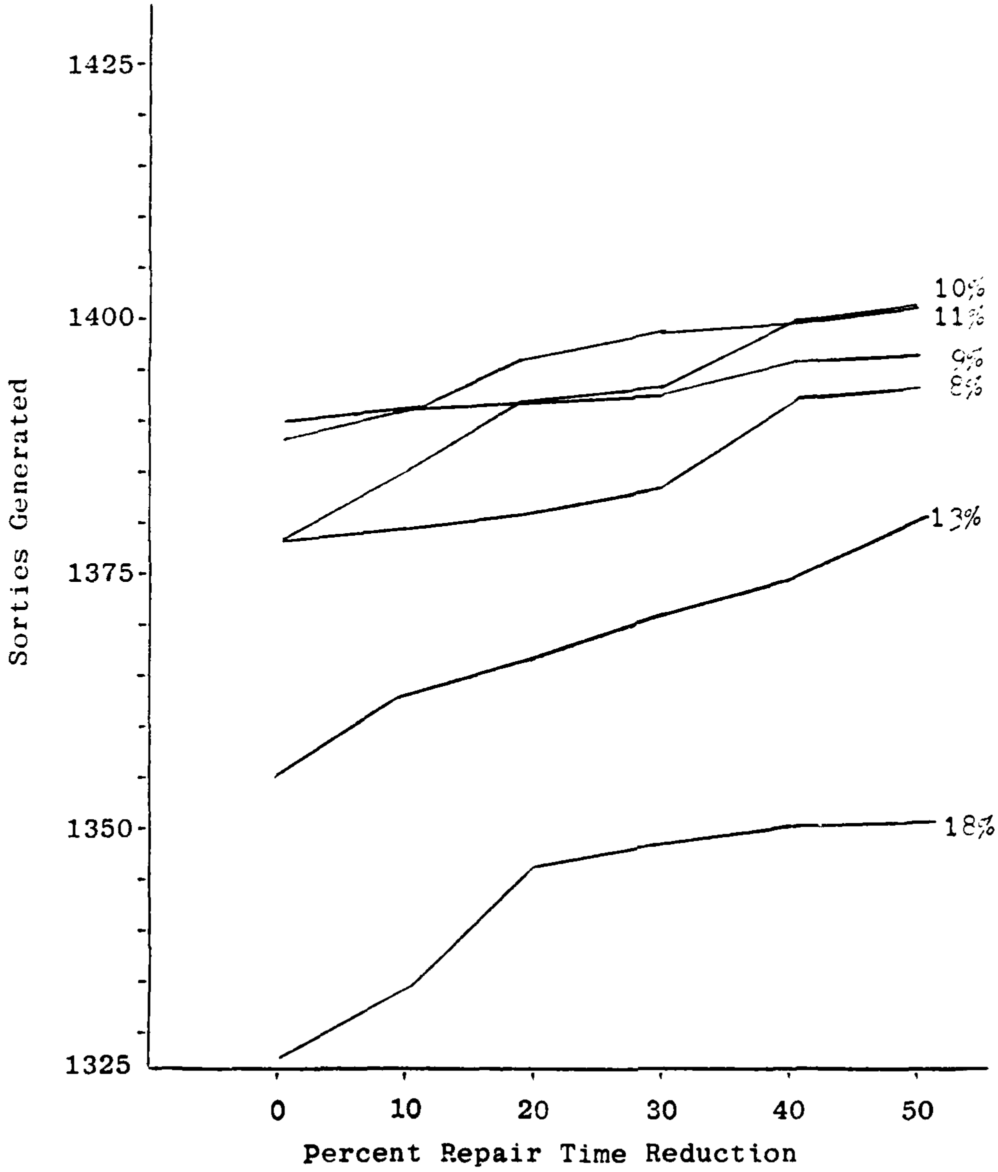


Figure 10. Sorties Generated Versus Percent Repair Time Reduction

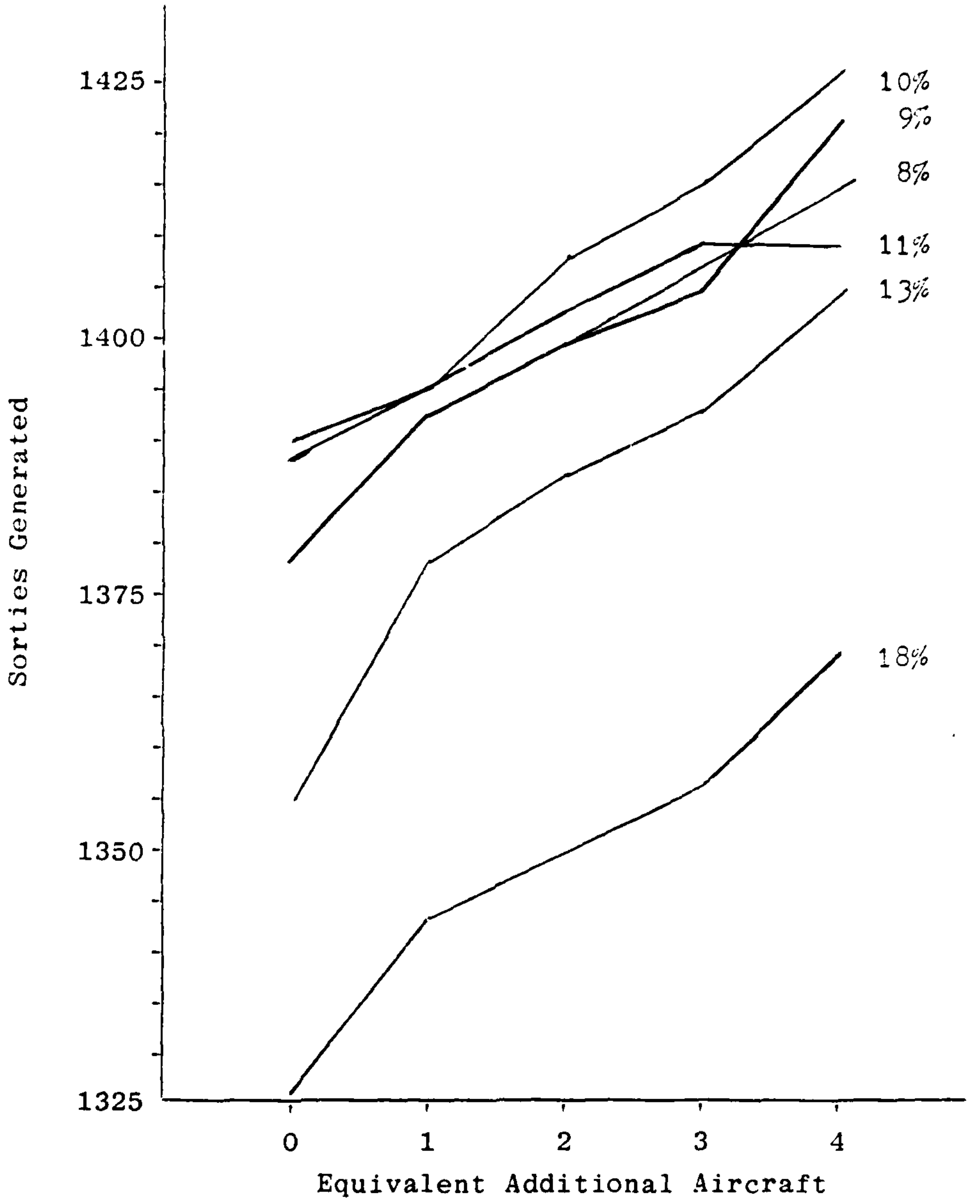


Figure 11. Sorties Generated Versus
Equivalent Additional Aircraft

rate curve fell above the 8 percent curve. To further the investigation, data was generated for 9 percent and 11 percent damage rates. They also fell either above or about the 8 percent curve.

At first, these results were not intuitively obvious. Since this data was summary data, an investigation into the results of each simulation run was begun. We found that at the lower damage rates, less than 13 percent, there were relatively more occurrences of the maximum number of sorties generated (Finding #1). This tended to bias the average value.

Finding #4. Thinking that the data was also biased by the sample size of ten, data was generated on a selected basis for a sample size of 35. The results were the same as Finding #3; hence, sample size was not the cause of the bias.

Finding #5. Figure 12, Additional Aircraft Versus Percent Repair Time Reduction, depicts the relationship between the two independent variables with the dependent variable of sorties generated as the common link. These curves were developed by equating the regression analysis results from each of the curves in Figures 10 and 11. These results, while positive in nature, do not show any logical sequencing to the family of curves.

Aircraft Waiting To Fly Approach

Johnson's study which used sorties generated was a good starting point but provided a limited measure of

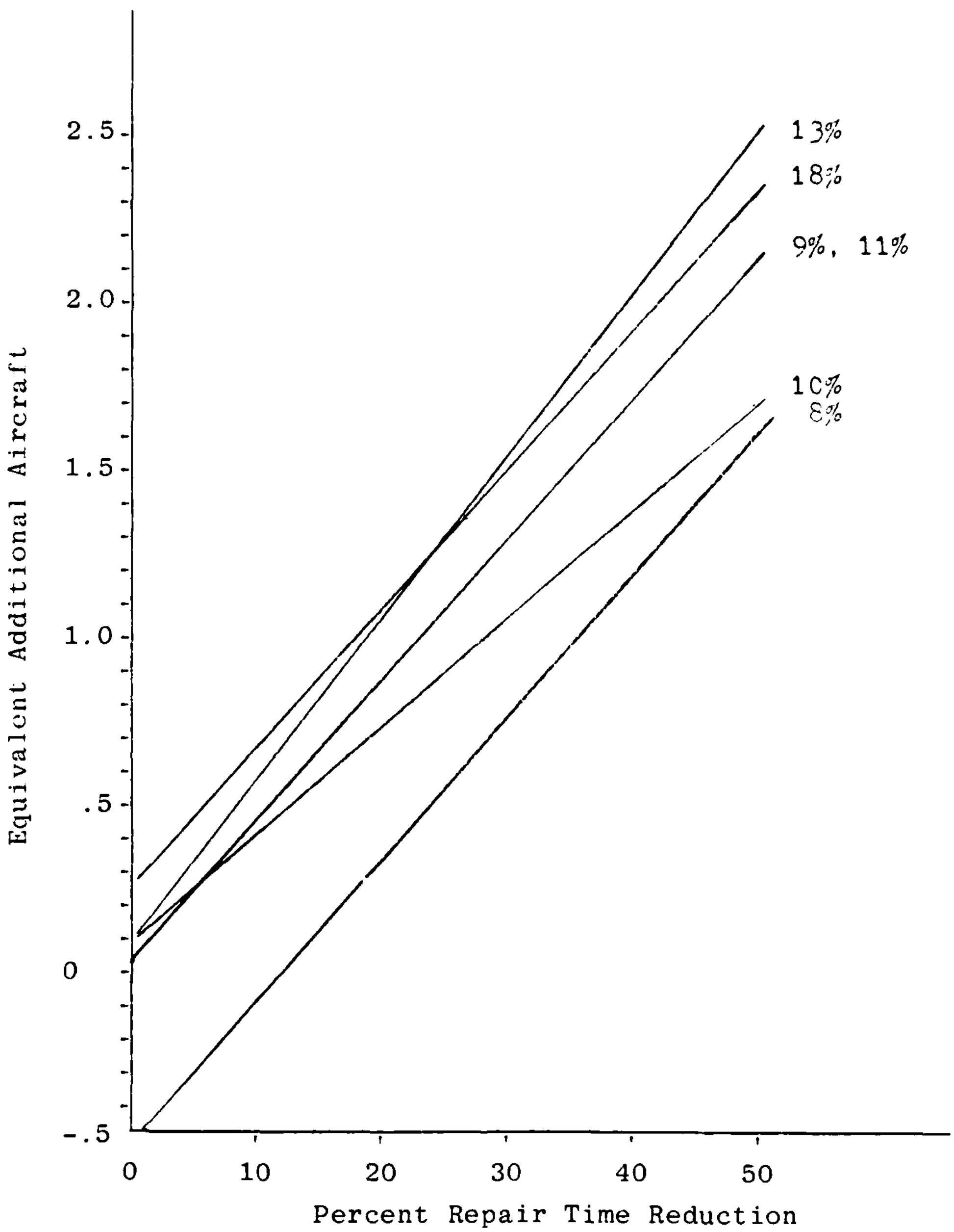


Figure 12. Equivalent Additional Aircraft Versus Percent Repair Time Reduction (Sorties Generated in Common)

aircraft availability because the results are biased based on a demand for aircraft which is greater than the supply. By using the number of aircraft waiting to fly in the model's queue, the impact of demand is omitted from the results. The data comes from the queue node 6 and represents the average number of aircraft fully available to fly a sortie. Once an aircraft has landed and has gone through the maintenance turn around cycle, it goes into the queue waiting for its next mission. After an aircraft has been repaired, it enters the normal maintenance turn around cycle.

Finding #6. There is a maximum and minimum number of aircraft possible in the queue. At the start of the simulation, since all aircraft are immediately available and missions are scheduled only every half hour, the maximum number in the queue is the number of aircraft at the simulation start minus one. The minimum number in the queue is zero aircraft. This situation occurs late in the simulation after the majority of aircraft have been lost (Finding #2). Remembering the averaging techniques used in Q-GERT, the number of aircraft waiting to fly is the average number available over the entire 30 days, not the average number available at any point in time.

Finding #7. As in Finding #3, damage rates of 8 percent, 13 percent, and 18 percent generated model results as expected. Figures 13 and 14 depict these relationships. To verify the sequence of curves, data for damage rates of

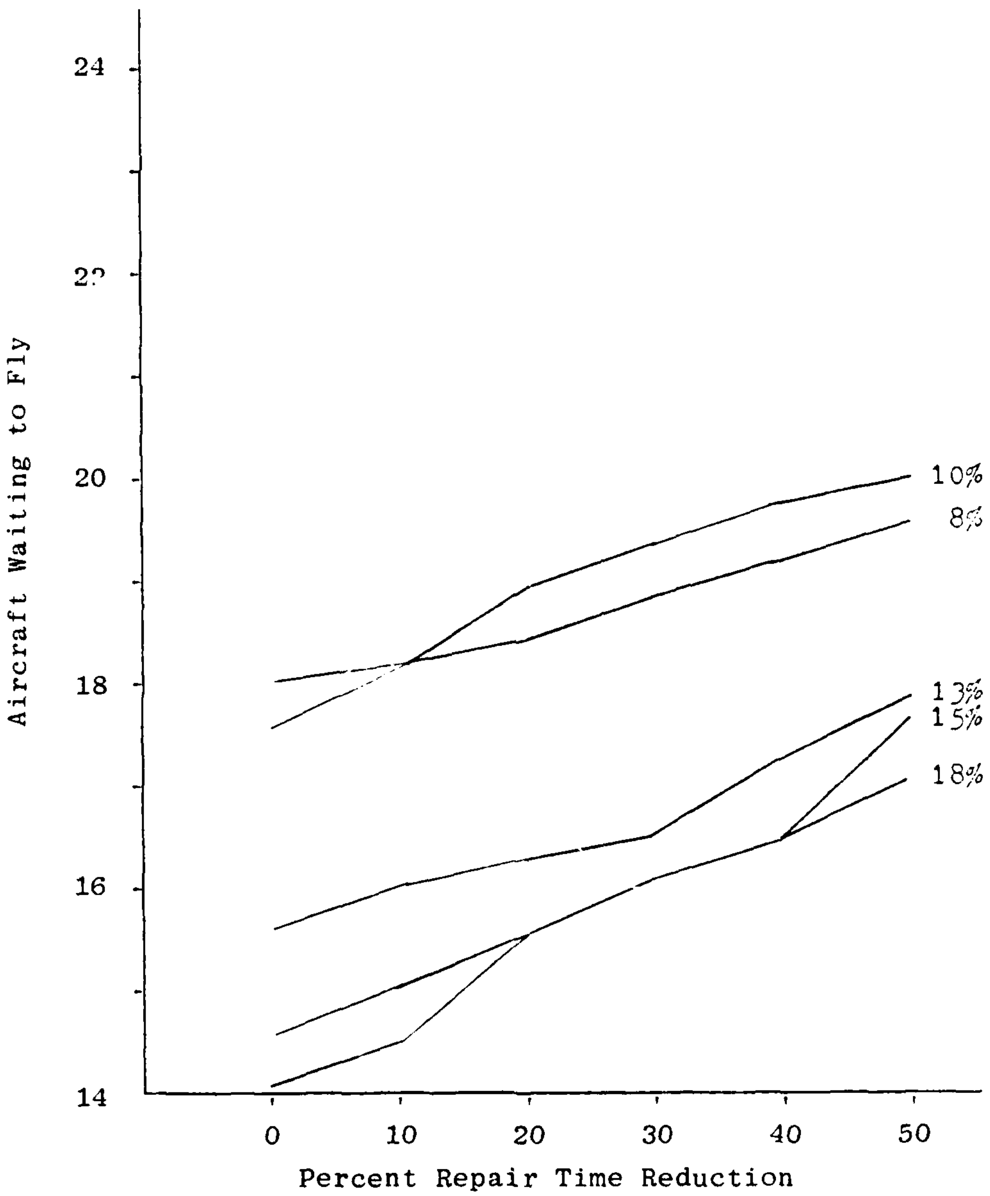


Figure 13. Aircraft Waiting to Fly Versus Percent Repair Time Reduction

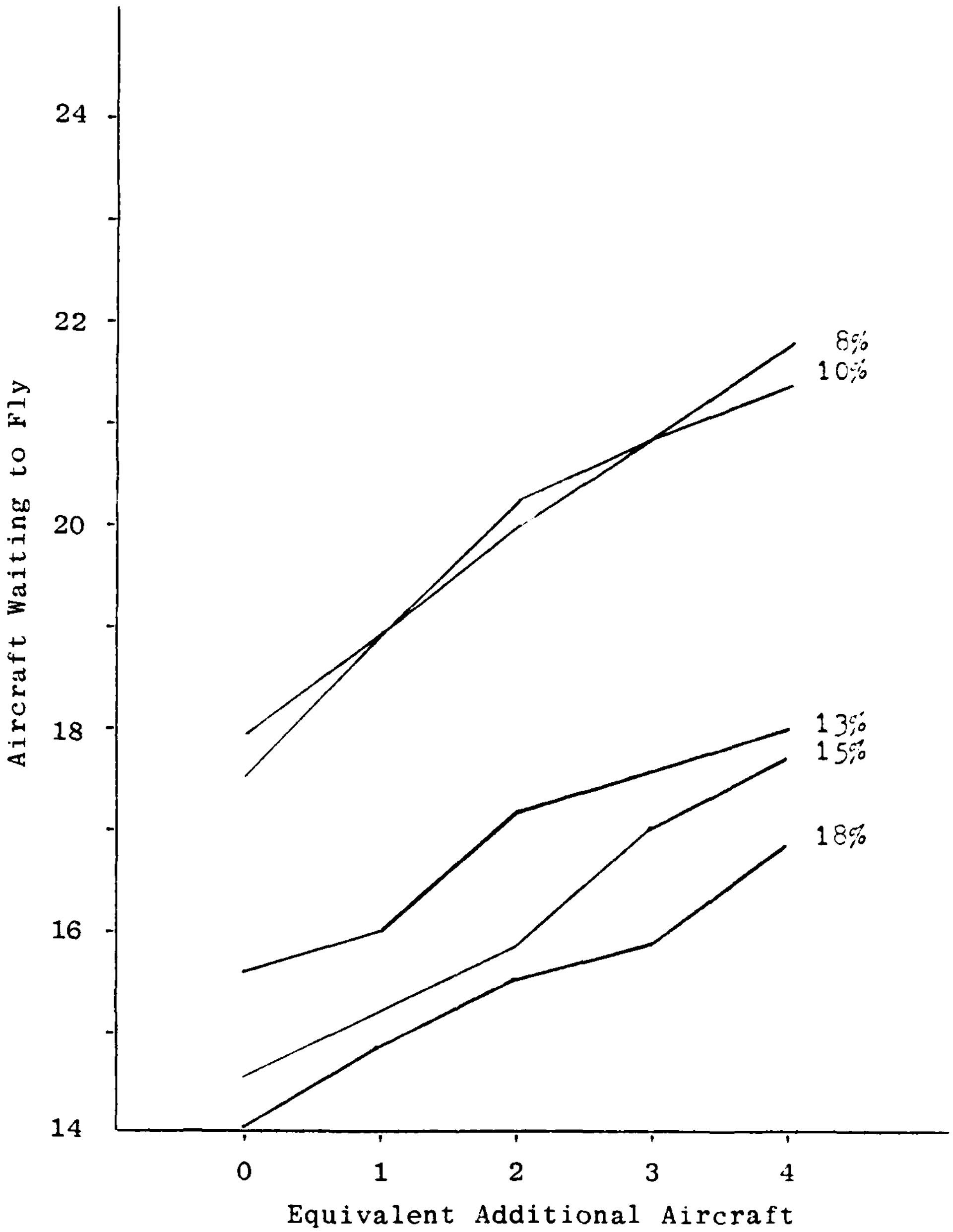


Figure 14. Aircraft Waiting to Fly Versus Equivalent Additional Aircraft

10 percent and 15 percent were generated. Again, unexpectedly, these curves did not fall between the existing curves, but rather they crossed the upper and lower curves. This phenomena was marked by the similarity in the data distributions with one or two relatively low values and one or two relatively high values causing a large standard deviation.

Finding #8. Figure 15, Additional Aircraft Versus Percent Repair Time Reduction, depicts the relationship between the two independent variables with the dependent variable of aircraft waiting as the common link. These curves were generated by equating the regression analysis results from the curves in Figures 13 and 14. These results do show a logical sequence to the family of curves progressing from an 8 percent damage rate up to 18 percent. Each curve is positively sloped and only at the lower values is there any crossing of the curves.

Calculated Availability Approach

Next, the possibility of calculating aircraft availability using Eq (6) was investigated.

$$A = \frac{T_F + T_W}{T_{MC}} \qquad (6)$$

The data comes from the Q-GERT model results. Flying time (T_F) is a constant of 1.0 hour. Waiting time (T_W)

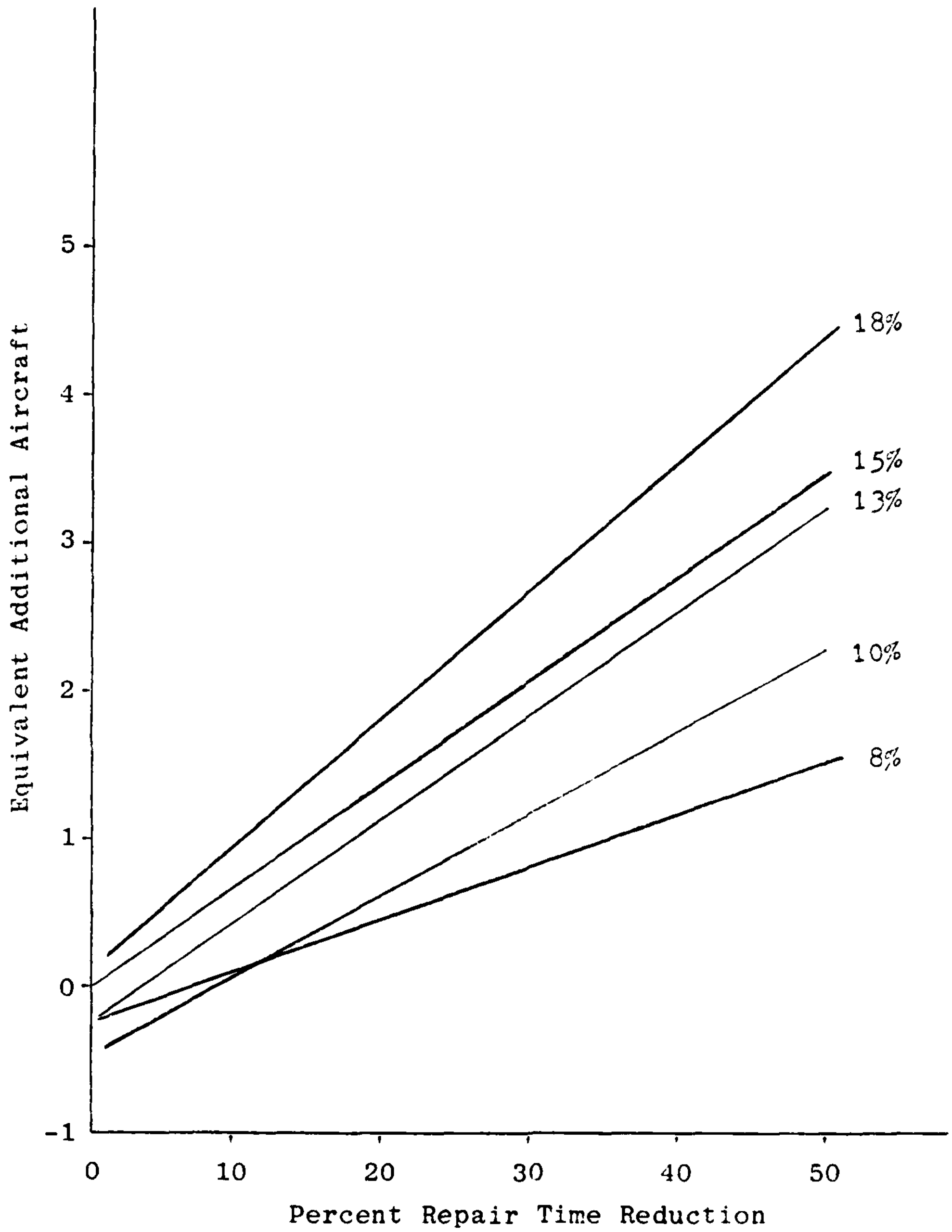


Figure 15. Equivalent Additional Aircraft Versus Percent Repair Time Reduction (Aircraft Waiting in Common)

comes from the queue node 6, the average time an aircraft is waiting to fly. Mission cycle time, or turn time (T_{MC}) comes from node 7, the turn time statistics node.

Finding #9. Figure 16 depicts the 8 percent, 13 percent, and the 18 percent damage rates for aircraft availability versus percent repair time reductions. As expected, as the damage rate increases, aircraft availability decreases. Also as repair time is reduced, availability is increased.

Finding #10. Figure 17 depicts the 8 percent, 13 percent, and the 18 percent damage rates for aircraft availability versus additional aircraft and increasing availability exists as expected. However, the slope of these curves is extremely small. This happens because additional aircraft affects both waiting time (T_W) and turn time (T_{MC}) equally, while reduced repair time affects waiting time differently than it affects turn time. As aircraft are added, both waiting time and turn time increase. Hence, availability does not change appreciably and the small slope results. However, as repair time is reduced, waiting time increases but turn time decreases, thereby causing a larger change in availability. This apparent discrepancy occurs because more aircraft are in the system without a reduction in repair time.

Finding #11. Figure 18, Additional Aircraft Versus Percent Repair Time Reduction, depicts the relationship between the two independent variables with the dependent

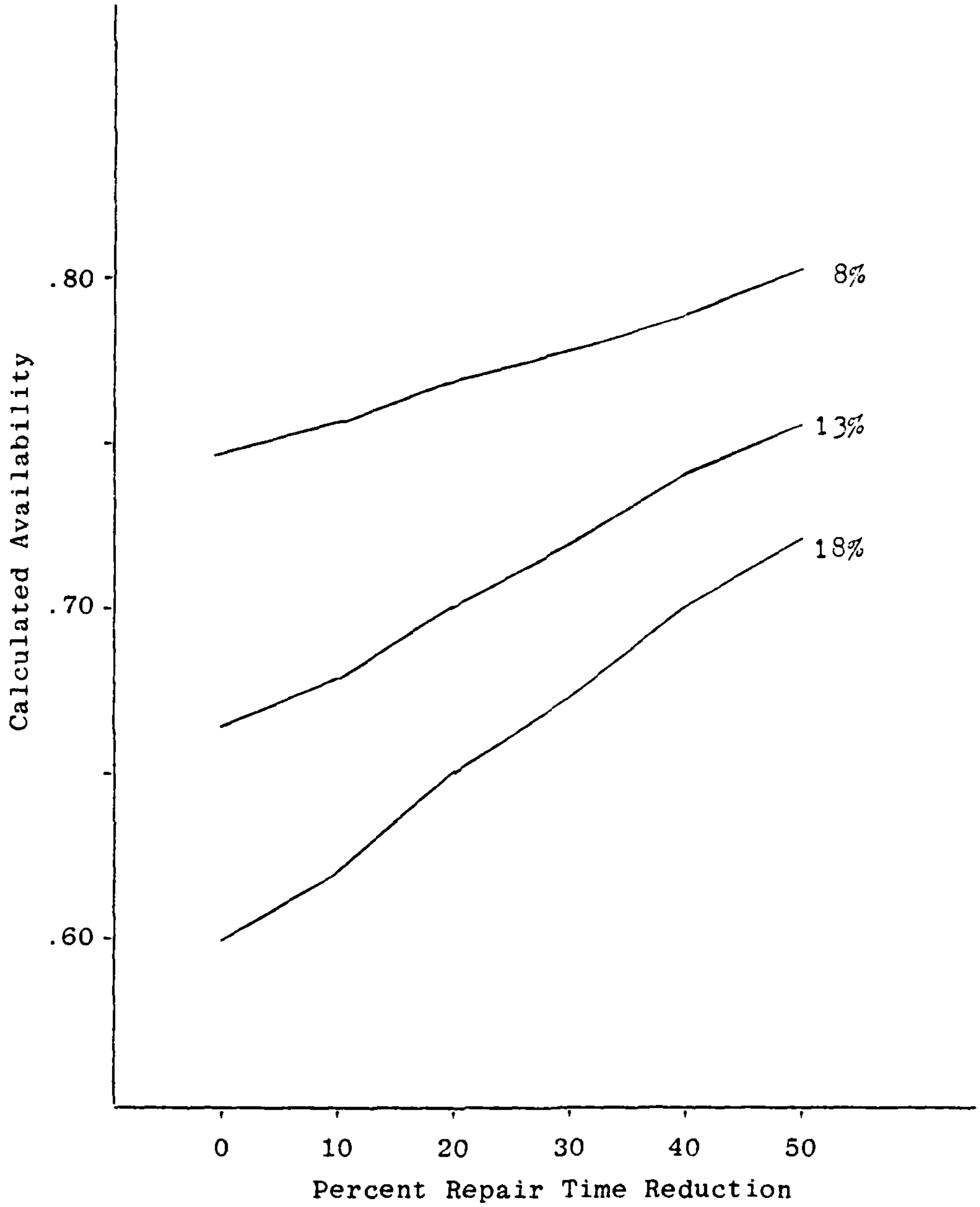


Figure 16. Calculated Availability Versus Percent Repair Time Reduction

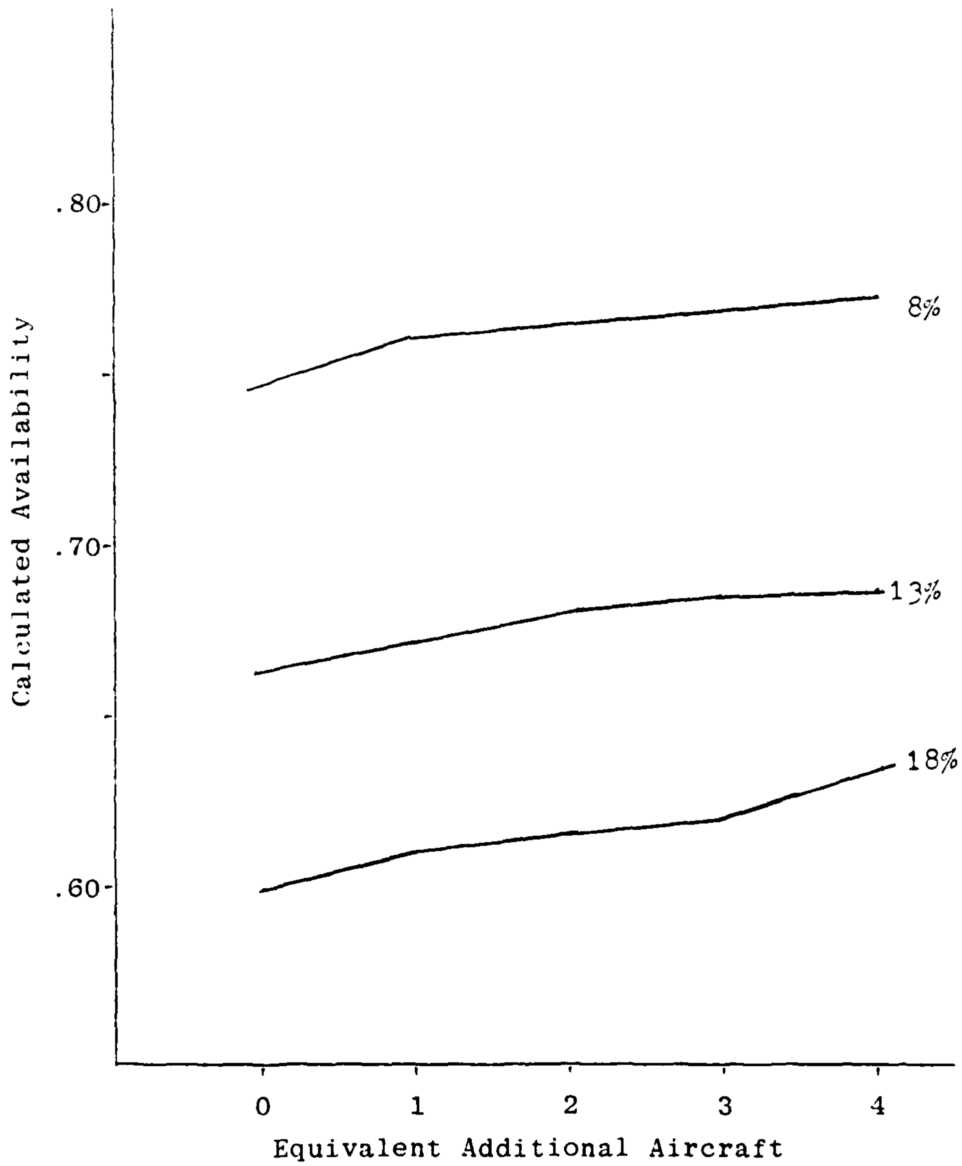


Figure 17. Calculated Availability Versus Equivalent Additional Aircraft

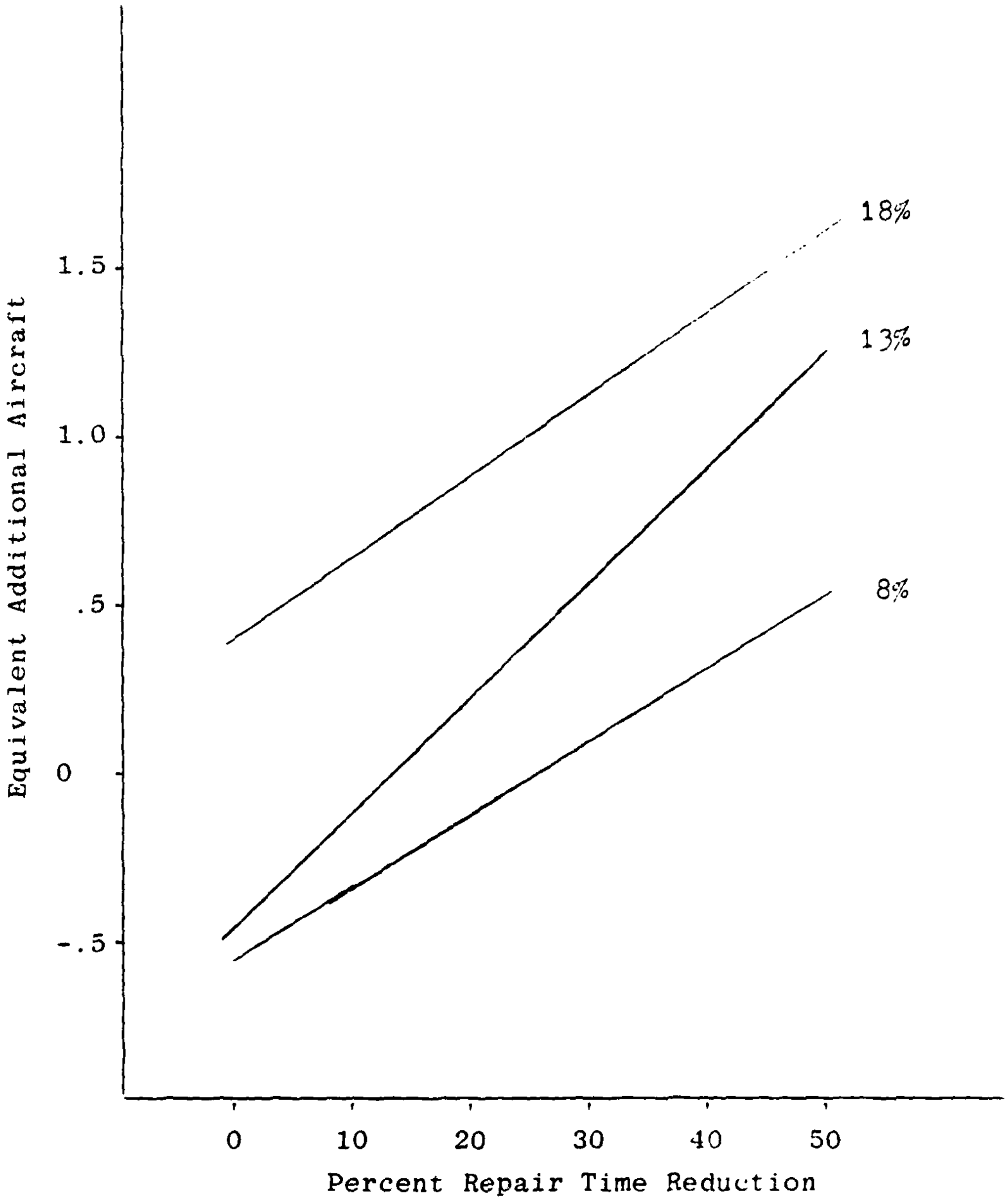


Figure 18. Equivalent Additional Aircraft Versus Percent Repair Time Reduction (Calculated Availability in Common)

variable of calculated availability as the common link. These curves are generated by equating the results from the regression analysis of the curves in Figures 16 and 17. Whereas each curve is positively sloped, a common family of curves is not apparent. Further, the 8 percent and 13 percent damage rates imply, at lower repair time reductions, a negative impact on additional aircraft. This is caused by the small slope of the additional aircraft curve with respect to calculated availability.

Findings on Research Question #1

Research Question #1. How sensitive is aircraft availability to reduced maintenance times?

Finding #12. The SPSS t-Test for groups was run for the 10 percent, 13 percent, 15 percent, and 18 percent damage rates comparing the 10 percent reduction intervals of repair time to the baseline. The number of aircraft waiting was the dependent variable. Table 1 shows the results for a one tail t-Test at an alpha level of .10. "Reject" means that the null hypothesis (the mean values are the same) is rejected in favor of the alternative hypothesis (one mean is greater than the other). In this thesis, a "Reject" means that a percent repair time reduction condition yields a significantly greater number of aircraft waiting than the baseline does. At a damage rate of 10 percent, all tested conditions of repair time reductions are significantly greater than the baseline. At 13 percent, only the

TABLE 1

t-Test Results (one tail), Baseline with Percent Repair Time Reduction

TIME RED.	DAMAGE RATE							
	10%		13%		15%		18%	
10%	--	--	.419		.343		.357	
20%	.071	Reject	.438		.231		.667	
30%	.021	Reject	.335		.137		.106	
40%	.013	Reject	.139		.082	Reject	.079	Reject
50%	.006	Reject	.073	Reject	.026	Reject	.035	Reject

50 percent reduction is significant. The 13 percent damage rate results were unexpected. We expected that the results would fall between the results for the 10 percent and 15 percent damage rates. Again, the relatively wide distribution of values as compared to the baseline distribution caused the unexpected results.

Findings on Research Question #2

Research Question #2. Can increased availability through reduced maintenance time be related to equivalent additional aircraft? If so, should this relationship be addressed as an acquisition decision strategy?

Finding #13. The SPSS t-Test for groups was run comparing the equivalent additional aircraft (+1, +2, +3, +4) results with the baseline. The number of aircraft waiting to fly was the dependent variable. Table 2 shows the results for a one tail t-Test at an alpha of .10. "Reject" has the same definition as in Finding #9. At a damage rate of 10 percent, all equivalent additional aircraft cause the number of aircraft waiting value to be significantly greater than the baseline condition. Damage rates of 13 percent and 15 percent show the significance at +3 and +4 additional aircraft. The 18 percent damage rate shows the significance at +4 aircraft.

Finding #14. The SPSS Regression Analysis was run for the percent repair time reduction with the dependent variable as the number of aircraft waiting to fly. Table 3

TABLE 2

t-Test Results (one tail), Baseline with Equivalent Additional Aircraft

ADD. A/C	DAMAGE RATE							
	10%		13%		15%		18%	
+1	.039	Reject	.379		.238		.298	
+2	.001	Reject	.212		.148		.152	
+3	.001	Reject	.082	Reject	.027	Reject	.104	
+4	.000	Reject	.083	Reject	.010	Reject	.038	Reject

shows the results of the regression analysis using percent repair time reduction as the independent variable. At all the damage rates, the null hypothesis (the coefficients are zero) is rejected in favor of the alternative hypothesis (the coefficients are not zero). That is, at an alpha level of .10 (table F value: $\alpha/2 = .05$) (23:638), the coefficients for the equations of aircraft waiting, at each damage rate, are significantly nonzero. The high R^2 and high $\bar{R}^2$ values indicate that these results are significant.

TABLE 3

F Test Results, Percent Repair Time Reduction

DAMAGE RATE	R^2	$\bar{R}^2$	GLOBAL F	TABLE F	TEST
10%	.985	.981	207.7	10.13	Reject
13%	.976	.970	161.1	7.71	Reject
15%	.982	.978	227.1	7.71	Reject
18%	.989	.986	378.6	7.71	Reject

Finding #15. The SPSS Regression Analysis was run for equivalent additional aircraft with the number of aircraft waiting to fly as the dependent variable. Table 4 shows the results. Again, at all the damage rates, the null hypothesis is rejected in favor of the alternative hypothesis. The high R^2 and $\bar{R}^2$ values also indicate that these results are significant.

TABLE 4

F Test Results, Equivalent Additional Aircraft

DAMAGE RATE	R^2	$\bar{R}^2$	GLOBAL F	TABLE F	TEST
10%	.929	.906	39.7	10.13	Reject
13%	.968	.958	91.6	10.13	Reject
15%	.995	.993	642.8	10.13	Reject
18%	.991	.988	335.4	10.13	Reject

Finding #16. Since the individual equations were found to be significantly nonzero, the equations can be equated to each other using the transitive law. Table 5 has the coefficients for the percent repair time reduction equation for damage rates of 10 percent, 13 percent, 15 percent, and 18 percent. Table 6 has the equations for the additional aircraft equations. Table 7 has the results of combining the values from Tables 5 and 6. Figure 19 graphically shows how these four damage rates create a sequential family of curves. These curves demonstrate that as repair time is reduced, the number of equivalent additional aircraft is increased.

Finding #17. Using the temporary repair procedures for the A-10 aircraft relative to the baseline (a 40 percent repair time reduction), the equivalent number of additional aircraft are 1.8, 2.6, 2.7, and 3.6 aircraft for damage rates of 10 percent, 13 percent, 15 percent, and 18 percent respectively.

TABLE 5

Coefficients - Repair Time Reduction

DAMAGE RATE	COEFFICIENTS	
	INTERCEPT	SLOPE
10%	17.69	.0493
13%	15.51	.0437
15%	14.35	.0567
18%	14.08	.0604

TABLE 6

Coefficients - Equivalent Additional Aircraft

DAMAGE RATE	COEFFICIENTS	
	INTERCEPT	SLOPE
10%	17.99	.914
13%	15.65	.614
15%	14.40	.829
18%	14.07	.671

TABLE 7

Coefficients - Combined Equations

DAMAGE RATE	COEFFICIENTS	
	INTERCEPT	SLOPE
10%	-.328	.054
13%	-.241	.071
15%	-.060	.069
18%	.015	.089

Equivalent Aircraft = Intercept + Slope * Percent Reduction

Validity

Finding #18. Internal validity was found to be present. The Q-GERT simulation model reflects real world sequencing of activities based on personal interview with HQ AFLC personnel. No errors were found in the logical sequence of events. The sample size was small and could have resulted in erroneous results. However, a sensitivity analysis based on 35 samples for the sorties generated approach showed no indication of erroneous results. The results were completely consistent throughout all manipulations of the data. The variances can be assumed to be essentially small since small variances generally exist with a central tendency model.

Finding #19. The simplicity of a model might detract from the external validity of the thesis by taking away real world probabilities. However, in this thesis, the basic

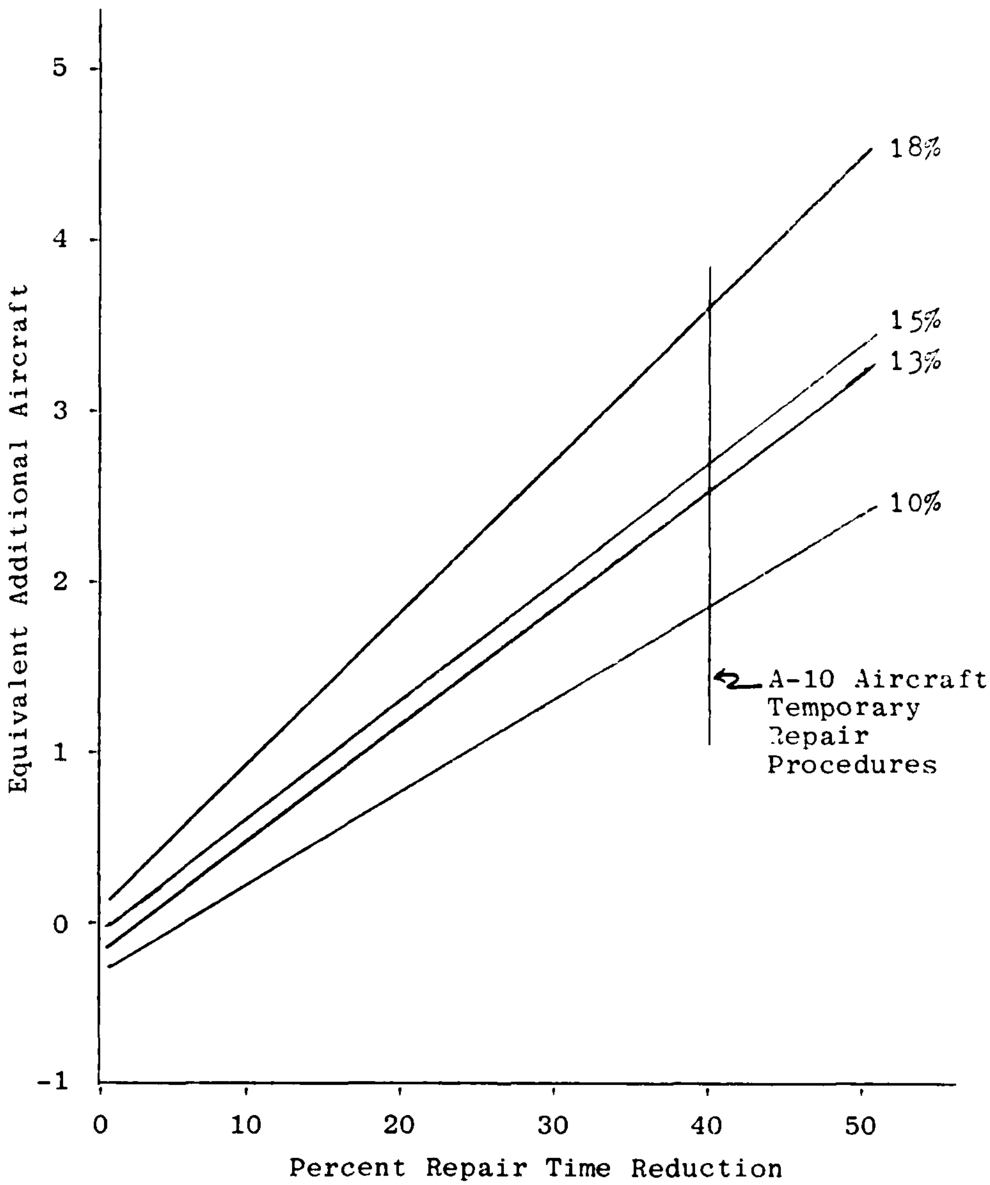


Figure 19. Equivalent Additional Aircraft Versus Percent Repair Time Reduction (Aircraft Waiting in Common)

relationship remains dominant and in the same direction. Any change to the assumptions such as limited personnel or spares, would likely make the situation worse and the findings all the more valid. For example, there will be fewer aircraft waiting to fly causing a greater impact on availability. Therefore, since the model is a best case or optimum situation, external validity is not sacrificed by the limiting assumptions made in the model.

Reliability

Finding #20. The procedures conducted in this thesis are repeatable which adds reliability to this thesis. However, the results are generic to the A-10 only. Because of the existing significance of the relationship between maintenance time reduction and addition of aircraft, the study of other aircraft is warranted.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the findings from Chapter 4 in the form of conclusions and recommendations for Research Questions 1 and 2. In addition, this thesis concludes with an overview of strategies for further study.

Conclusions - Research Question #1

Research Question #1. How sensitive is aircraft availability to reduced maintenance times?

Table 8 shows the additional number of sorties which can be generated by reducing maintenance time. These additional sorties are averages for the 30 day scenario and a 48 aircraft squadron as used in the model. There are dramatic increases in additional sorties, especially for the higher damage rates.

TABLE 8

Additional Sorties Generated

Damage Rate	Percentage Reduction in Maintenance Time					
	0%	10%	20%	30%	40%	50%
8%	0	.6	3.2	4.5	15.3	16.6
13%	0	6.4	11.2	15.1	19.5	27.1
18%	0	8.6	19.3	21.2	23.3	25.6

Because of the variability in the data results of the model, the sorties generated and the calculated availability approaches were not adequate to answer Research Question #1 with certainty. These were dropped in favor of the number of aircraft waiting to fly approach. This can be considered a shift in focus from the demand aspect of sorties required to the supply aspect of aircraft waiting to fly.

The sensitivity of aircraft availability, as measured by the number of aircraft waiting to fly, with respect to reduced maintenance time, is related to the aircraft damage rate. Generally, the lower the damage rate, the greater the effect a given repair time reduction has on availability. From the t-Test results, the sensitivity is statistically significant at the higher percent reduction maintenance time. It is therefore concluded that there is a significant positive relationship between availability and the percent reduction in repair time.

Recommendation - Research Question #1

Because of the variability in using different types of measures of availability (i.e., supply and demand), there should be an investigation into other common links between reduced maintenance time and additional aircraft.

Conclusions - Research Question #2

Research Question #2. Can increased availability through reduced maintenance time be related to equivalent additional aircraft? If so, should this relationship be addressed as an acquisition decision strategy?

Additional aircraft, as a measure of availability, becomes statistically significant at the +3 aircraft level for all damage rates. Because both reduced maintenance time and additional aircraft are significantly related to availability, they can be equated to each other. Thus, reduced maintenance time can be quantified in terms of equivalent additional aircraft. Table 8 shows these relationships for maintenance time reductions of 10 percent, 20 percent, 30 percent, 40 percent, and 50 percent. Figure 21, Chapter 4, depicts these relationships.

The simulation model assumes an aircraft squadron of 48 aircraft with sufficient manpower and spares. The number of equivalent additional aircraft reflect the effect of repair time reductions on only one squadron. Therefore, as the number of squadrons increase, the total number of equivalent additional aircraft should increase. An underlying assumption is that the percent maintenance time reduction can be achieved across the board without an increase in manpower and spares. This amount of reduction could come from a change in maintenance procedures (such as Aircraft Battle Damage Repair) or from improved maintenance technology.

Another possibility would be to achieve these reductions through aircraft design considerations early in the acquisition cycle; it is possible to make relatively inexpensive changes to aircraft design and logistics support concepts. Figure 20 shows the relationship of percent design completion to the acquisition cycle. As the percent design completion approaches 100 percent, the cost of design change becomes prohibitive. Hence, it is more cost effective to change design early in the acquisition cycle.

As an acquisition decision strategy, the tradeoff between reduced maintenance time and equivalent additional aircraft could be used in determining where USAF resources should be placed. For example, the USAF could tradeoff procuring additional aircraft with research and development technology to reduce maintenance time, and, hence, increase the equivalent aircraft. It should be pointed out that technology development is mostly up front, one time costs which can be applied to future squadrons at little or no additional cost. However, without the technology, future squadrons would have to procure that many more new aircraft. The resource tradeoff becomes more dramatic as the number of squadrons is increased.

Recommendation - Research Question #2

Evaluate the sensitivity of the various logistics policies which may cause fluctuations in maintenance time. For example, are the amount of materiel and spares in the

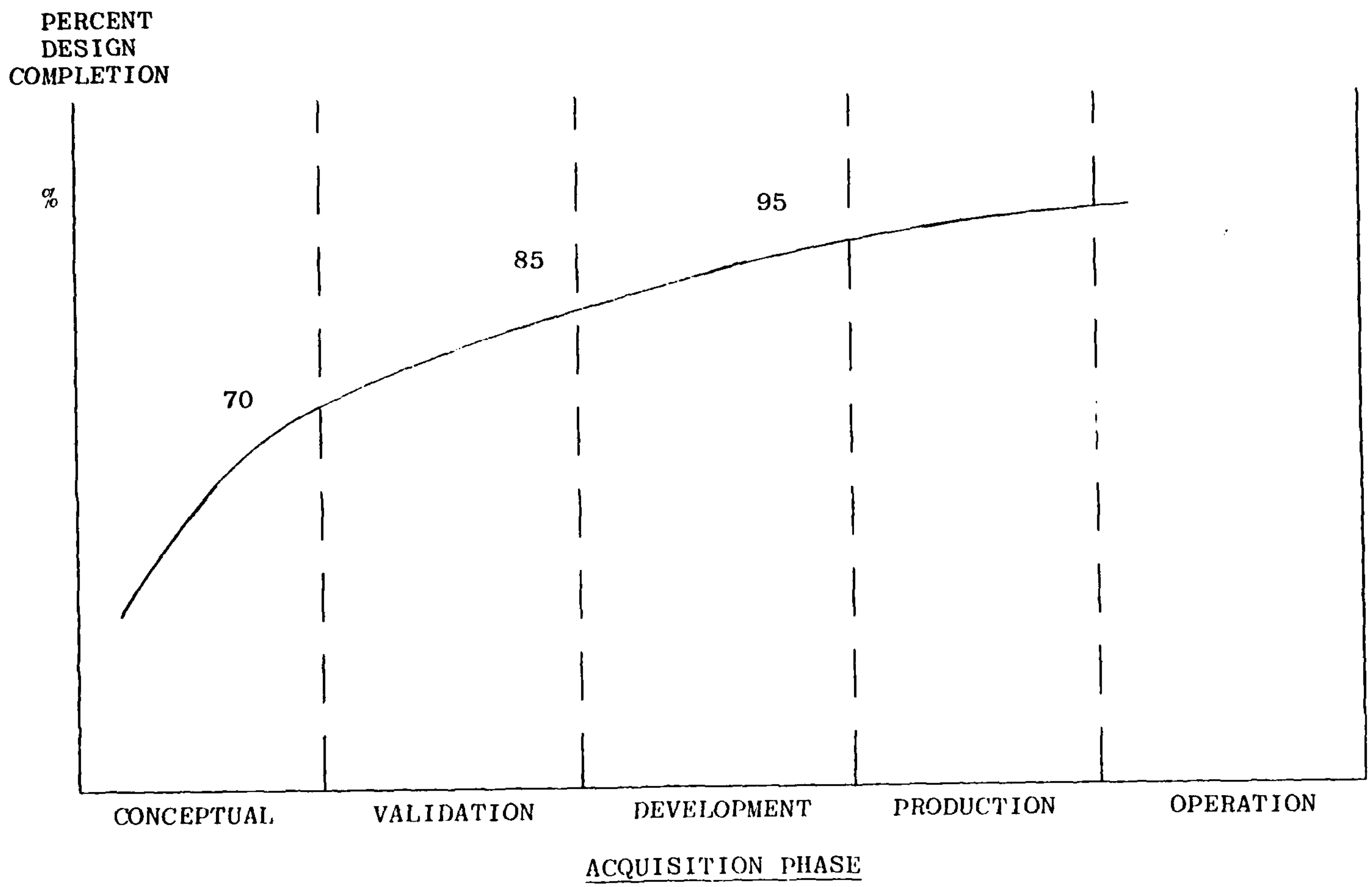


Figure 20. Percent Design Completion Versus Acquisition Phase

WRSK sufficient to support a 30 day war scenario? Can maintenance personnel be cross trained in more than one specialty? What are the logistics policies which would enhance the notion of equivalent aircraft? What are the policies which would inhibit an increase in equivalent additional aircraft?

Strategies for Further Study

As in most thesis work, there are both strong points and weak points in this thesis. The two most notable weak points are: one, the lack of variety in input data; and two, the limitations on external validity as caused by the type and number of assumptions. To fortify the thesis conclusions and future application of its findings, the following is recommended.

Recommendation #1. The input data should be extended beyond just the A-10 data. Other aircraft types, such as fighter and cargo, should be evaluated. Most existing maintenance data is presently based on work coded components and not on total aircraft clock downtime. This data needs to be modified and manipulated to answer the research questions. Proper data collection procedures need to be designed to eliminate this problem in future research.

Recommendation #2. The Q-GERT model itself was simplified by keeping the confounding variables constant. This made aircraft availability dependent only on the independent variables of reduced maintenance time or additional

aircraft. Many of the assumptions in Chapter 3 are based on discussions with various HQ AFLC personnel with maintenance background. Assumptions were made such as sortie length of one hour, normal maintenance turnaround time of one hour and a 24 hour maintenance day. These assumptions should be studied and the variables added to the model when necessary for scenarios other than the one depicted in this thesis.

The important question here is whether the model assumptions invalidate the application of the model to the real world. The model, through its simplicity, creates a best case situation. Any addition of confounding variables would make the situation less than optimum and the results of this thesis all the more valid. Therefore, the model is externally valid even though simplified.

Recommendation #3. Peacetime is important because the Air Force trains and operates under peacetime conditions most of the time. As such, peacetime should be considered. The sensitivity of the model's results may be directly affected by using peacetime instead of wartime conditions. And the peacetime results may affect the application of aircraft availability as an acquisition study. For example, the lack of flying schedule intensity, or built-in clock time delays between scheduled flights may reduce or eliminate the benefit of reduced maintenance time. If it does, then the Air Force strategy might be to develop wartime only

maintenance reduction policies instead of across-the-board policies. Also, instead of using aircraft availability as an acquisition strategy for aircraft systems, the USAF may want to focus on logistics policies to enhance its wartime support posture.

Recommendation #4. One possible method tying recommendations 1, 2, and 3 together is to set up a series of operational exercises. Use of existing sortie surge or Red Flag exercises could provide real world test conditions. Normal operations of the same units could provide a reference baseline condition. Since aircraft attrition and battle damage does not normally occur during these exercises, a predetermined matrix of attrition and clock downtimes for battle damage repair would have to be generated. This matrix would then be used to levy "battle conditions" on the surge exercises.

The development of this matrix would be subjected to the same scrutiny of data validity and assumptions that bound this thesis. The results however, would provide a real world assessment on the actual impact of reduced maintenance time as equivalent to additional aircraft. A series of exercises could be used to generate the various levels of battle damage rates, reduced maintenance times, and additional aircraft.

Recommendation #5. If the results of the above recommendations are consistent with this thesis, then, and

only then, should implementation be considered. Implementation of aircraft availability as an acquisition strategy requires a two pronged approach. The first approach concerns the theoretical feasibility of attaining a 30 to 50 percent reduction in maintenance time. Can technology be advanced such that a reduction of this magnitude is possible? Are there management policies which could enhance a reduction in maintenance time or can the Air Force build and configure aircraft to enhance a maintenance time reduction?

The second approach concerns the practicality of incorporating these new found ways of maintenance time reduction in the field. Will more people with higher skills be needed or can new technology also reduce the manpower requirements? Will dependence upon exotic materials and special tools be increased or decreased? What is the impact of chemical or biological warfare on maintenance?

The list of considerations is endless. The practicality of using any change in maintenance in the field, be it policy or technology, must be addressed up front as a development requirement.

Concluding Remarks

In conclusion, this thesis has found a positive relationship between reduced maintenance time and equivalent additional aircraft for wartime conditions based on A-10 data.

If an A-10 squadron deployed tomorrow to a shooting war in the Middle East, they would be called upon to operate

in harsh conditions and with austere maintenance and supply support. What figure of merit should one use to judge how much special emphasis to place on maintenance crews and procedures or on supply pipelines? This thesis shows that, for a realistic damage rate of 13 percent, an A-10 squadron operations officer would be able to generate 15 more sorties per month if the maintenance officer was able to reduce maintenance time by 30 percent. A 50 percent reduction would yield 27 additional sorties. Battle damage repair teams seek to get an aircraft minimally able to fly a given set of sorties (e.g., the lights can remain shot out for a daytime sortie). This type of effort, and a whole range of shortcut procedures beneath it can be considered if 15 (or 27) sorties are deemed worth pursuing.

Maintenance time reduction can either be achieved through better operations or designed into a system before it is fielded. An acquisition program, by concentrating on aircraft maintenance accessibility and simplicity in development, would be able to effectively increase the wartime availability of aircraft by the figures just described. This has the equivalent effect of purchasing additional aircraft, but with the benefit of a lower comparative investment cost.

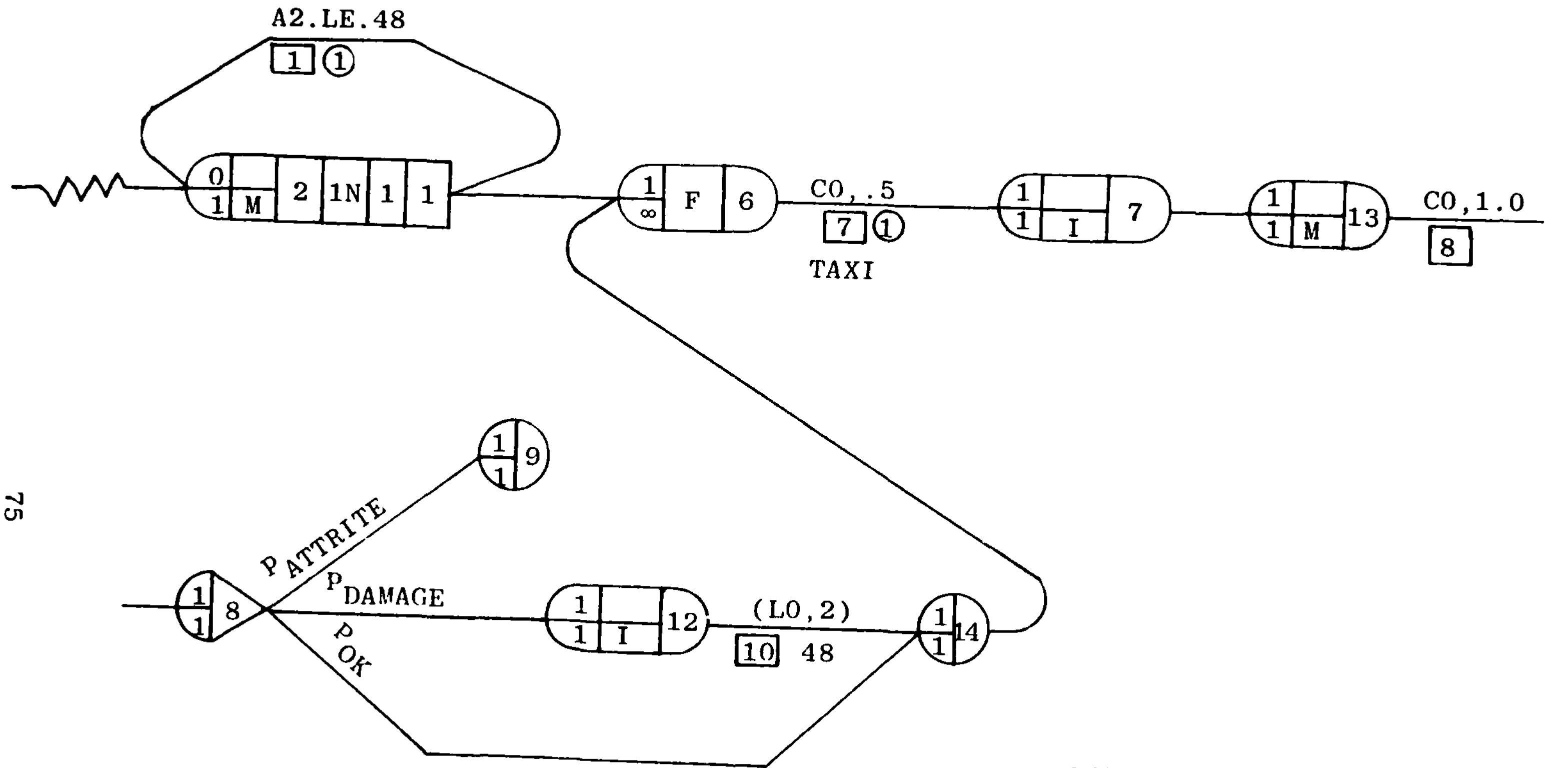
APPENDIX A

SIMULATION MODEL

TABLE 9

Listing of Model Runs

Damage Rate	Percent Repair Time Reduction						Increase in Baseline Aircraft				
	B.L.	10	20	30	40	50	+1	+2	+3	+4	+5
8	X	X	X	X	X	X	X	X	X	X	X
9	X	-	X	X	X	X	X	X	X	X	-
10	X	-	X	X	X	X	X	X	X	X	-
11	X	-	X	X	X	X	X	X	X	X	-
13	X	X	X	X	X	X	X	X	X	X	X
15	X	X	X	X	X	X	X	X	X	X	X
18	X	X	X	X	X	X	X	X	X	X	X



NOTE: Unless otherwise noted, all transactions are at CO,0.0

Figure 21. Q-GERT Network

```
*** INPUT CARDS ***

GEN,GILDEC,THESIS,6,2,1982,2,0,0,744,10,E,24,2,0,0,1,1,,E4*
SOU,1,0,1,A,M*
VAS,1,2,IN,1*
ACT,1,1,CO,0.0,1/GENAC,1,,A2.LE.48*              AC PLUS 1
ACT,1,6,CO,0.001,5/ACDELI*
QUE,6/WAIT2FLY,0,,D,F*
ACT,6,7,CO,.5,7/TAXI,1*
STA,7/TURNTIME,1,1,D,I*
ACT,7,13,CO,0.*
REG,13,1,1,D,M*
ACT,13,8,CO,1.,8/FLY,48*
REG,8,1,1,P*
ACT,8,9,CO,0.0,9/ATTRITE,1,.03*
REG,9,1,1*
ACT,8,14,CO,0.0,11/LANDOK,1,.79*                 DAM +5
ACT,8,12,LO,2,10/REPAIR,48,.18*                LOGNORMAL  DAM +5
PAR,2,20.53,2.,100.,14.25*                A10 BASELINE 0%
STA,12/REPTIME,1,1,D,I*
ACT,12,14,CO,0.0*
REG,14,1,1*
ACT,14,6,CO,1.0,15/ACTURN,48*
FIN*

*** NO ERRORS DETECTED IN INPUT DATA ***

*** EXECUTION WILL BE ATTEMPTED ***
```

GERT SIMULATION PROJECT THESIS   BY GILDEC
DATE 6/ 2/ 1982

FINAL RESULTS FOR FIRST SIMULATION

TOTAL ELAPSED TIME =   744.0000

NODE STATISTICS

NODE	LABEL	AVE.	STD.DEV.	NO OF OBS.	STAT TYPE
12	REPTIME	19.8450	12.0633	269.	I
7	TURNTIME	13.3195	10.8883	1338.	I

NUMBER IN Q-NODE   ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
6	WAIT2FLY	12.4329	0.	43.	0	6.6953

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
7	TAXI	1	0.9285	2.0000	440.0010

GERT SIMULATION PROJECT THESIS BY GILDEC
DATE 6/ 2/ 1982

FINAL RESULTS FOR 10 SIMULATIONS

AVERAGE NODE STATISTICS

NODE	LABEL	PROBABILITY	AVE.	STD.DEV.	SD OF AVE	NO OF OBS.	MIN.	MAX.	STAT TYPE
12	REPTIME	1.0000	21.8318	0.9212	0.2913	10.	19.8450	23.3802	I
7	TURNTIME	1.0000	14.6446	1.1612	0.3672	10.	12.7744	17.0894	I

		AVERAGE NUMBER IN Q-NODE					**AVERAGE WAITING TIME**			**NUMBER IN Q-NODE**
NODE	LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	MAX.
6	WAIT2FLY	14.7935	2.9389	0.9294	10.5315	21.0191	7.8854	1.2021	0.3801	43.0000

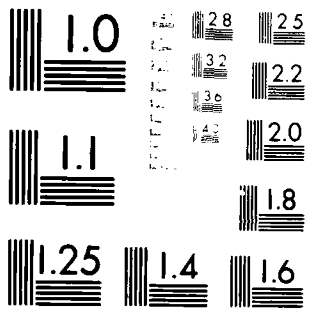
			AVERAGE SERVER UTILIZATION						**EXTREME VALUES**	
SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
7	TAXI	1	0.9330	0.0666	0.0211	10.	0.8201	0.9963	16.8807	656.5010

APPENDIX B

STATISTICS COMPUTER PROGRAMS

```
RUN NAME         REGRESSION 13% DAMAGE RATE
PRINT BACK       CONTROL
VARIABLE LIST    CODE,LEVEL,ACWAIT
INPUT FORMAT     FREEFIELD
INPUT MEDIUM     ACD13
N OF CASES       UNKNOWN
READ INPUT DATA
*SELECT IF       (CODE EQ 1)
REGRESSION       VARIABLES=ACWAIT,LEVEL
                 REGRESSION=ACWAIT WITH LEVEL
STATISTICS       ALL
```

```
REGRESSION 13% DAMAGE RATE
 -A I R   F O R C E   I N S T I T U T E   O F   T E C H N O L O G Y -
FILE     NONAME (CREATED   7 JUL 82  8:58:48)

* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * *

          DEPENDENT VARIABLE..      ACWAIT

          VARIABLE(S) ENTERED ON STEP NUMBER  1..      LEVEL


          MULTIPLE R           0.98781
          R SQUARE             0.97578
          ADJUSTED R SQUARE    0.96972
          STANDARD ERROR       0.14397


     ANALYSIS OF VARIANCE     DF      SUM OF SQUARES      MEAN SQUARE          F
     REGRESSION                1.            3.33977          3.33977     161.12667
     RESIDUAL                  4.            0.08291          0.02073


        ----------------- VARIABLES IN THE EQUATION ------------------

        VARIABLE          B          BETA     STD ERROR B      F

         LEVEL     0.4368571E-01    0.98781       0.00344    161.127
        (CONSTANT)   15.50619
```



MICROCOPY RESO TION TEST CHART

NATIONAL BUREAU STANDARDS A

```
RUN NAME       T-TEST 18%
PRINT BACK     CONTROL
VARIABLE LIST  BL,R10,R20,R30,R40,R50,AC1,AC2
INPUT FORMAT   FREEFIELD
INPUT MEDIUM   TDATA18
N OF CASES     UNKNOWN
T-TEST         PAIRS=BL WITH R10/BL WITH R20/BL WITH R30/BL WITH R40/
               BL WITH R50/BL WITH AC1/BL WITH AC2/
               R30 WITH AC1/R50 WITH AC2/
```

- T - T E S T - - - - - - - - - - - - - - - - - -

VARIABLE	NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.
BL	10	1325.8000	95.569	30.222	0.14	9	0.894
R10		1324.4000	94.652	29.931			
BL	10	1325.8000	95.569	30.222	-2.16	9	0.059
R30		1347.0000	104.272	32.974			
BL	10	1325.8000	95.569	30.222	-2.11	9	0.064
R40		1349.1000	106.065	33.541			

T - T E S T

VARIABLE	NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.
BL							
		1325.8000	95.569	30.222			
	10				-2.39	9	0.041
		1351.3000	97.111	30.709			
AC2							
R30							
		1347.0000	104.272	32.974			
	10				0.68	9	0.515
		1344.1000	95.692	30.261			
AC1							

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